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ROBERT WILHELM BUNSEN.

By HENRY CREW.

THE disappearance of a great leader of men marks, for all of us, a time of reckoning. For we naturally pause to consider what results of the man's work will live after him, what his sources of inspiration were, where lay his power, and even the most optimistic of us will ask, though in no ungracious spirit, whether another leader can be found. In the case of Robert W. Bunsen, who died at Heidelberg on the 16th of August, 1899, this reckoning is one of unusual interest to all students of science.

Each of the physical and natural sciences will probably always be likened to an unfinished structure. But in the case of chemistry we have good reason to think that the structure has at least reached the point where its foundations have been completed. If these foundations were begun by Lavoisier and Dalton, then Bunsen may be thought of as the last of that remarkable group of men, including Wöhler, Liebig, and Dumas, by whom this substructure was completed.

Bunsen was born at Göttingen on the 13th of March, 1811. Here he spent his early boyhood and received his university training, taking his doctor's degree at the age of twenty.

His father was a member of the theological faculty of this place. His education was continued at Paris, Berlin, and Vienna. At the age of twenty-two he began with a privatdocentship at Göttingen that marvelous career of teacher and investigator destined to extend over more than half a century, and to make his name beloved by his own students and a household word for all others. The years between 1836 and 1851 were spent principally in Cassel and Marburg; at the former place he succeeded Wöhler, at the latter he was succeeded by Kolbe. The laboratory which Bunsen started at Marburg in 1840 and that of Liebig at Giessen were among the very first of all those established for the instruction of students. The years from 1851 to 1899 were spent at Heidelberg.

A brief statement of only the more important of Bunsen's contributions to chemistry and related physical sciences would be something like the following:

1. He discovered the first member of a series of organometallic compounds, known as the *cacodyls*. It was the investigation of these poisonous, explosive, and ill-smelling compounds that cost him the sight of one eye. The work is reprinted in Ostwald's *Wiss. Klassiker*, No. 27; where its important bearing on the doctrine of radicals is set forth by the editor.

2. By the invention of the Bunsen battery the expensive platinum plate of the Grove cell was replaced by a cheap carbon rod. It is no easy matter for those of us who live in "the electrical age" to realize what a powerful aid this cell was to the teacher and to the investigator of those early days when dynamos were unknown and a current of more than a few amperes was rare and expensive.

3. The Bunsen burner is now in use everywhere from the kitchen to the research laboratory. There seems to be no doubt but that Bunsen was led to this invention purely by his thorough understanding of the principles of combustion. For his original description see *Pogg. Ann.*, **100**, 1856.

4. In 1847, after a trip to Iceland, he gave the only satisfactory explanation ever offered for the phenomenon of the

geyser. By lowering thermometers into the geyser-tube immediately before eruption he discovered the key to the whole situation, namely, that at no point in this column does the water reach its boiling point. When any considerable portion of the column of water is slightly elevated its pressure is correspondingly lowered; its boiling point is thus reduced to a temperature lower than the temperature of the water; the result is sudden evolution of steam and eruption. Much has been said against Bunsen's theory of geysers, but experiment shows beyond all question that the causes assigned by him are sufficient, if not necessary. (*Pogg. Ann.*, **72**, 1847.)

5. The chemistry of blast-furnace gases engaged his early attention and led practically to the creation of that branch of chemistry known as gas-analysis. These general results are embodied in his *Gasometrische Methode*, which appeared first in 1860, with a second edition in 1877. His work along this line is marked above all else by its precision.

6. The chemical action of light he studied in conjunction with Sir Henry Roscoe. This subject, like all others, was taken up in a careful, quantitative manner. Among other interesting results was an accurate measure of the sky-radiation in various latitudes extending from Egypt to Iceland, and for all hours of the day, from morning till evening. This research is well summarized in Watt's *Dictionary of Chemistry*.

7. His ice calorimeter is well known. English readers will find his original description translated in the *Phil. Mag.*, **41**, 161–182, 1871.

8. But the work for which Bunsen will, possibly, be longest remembered is that which he did with Kirchhoff in establishing the branch science of spectrum analysis.

The invention of the spectroscope considered as an instrument of research must undoubtedly be referred to Fraunhofer; and the physical basis upon which spectra are to be interpreted was first distinctly enunciated by Kirchhoff. What then were the contributions of Bunsen to this science?

Ostwald in an editorial note to his reprint of the joint papers

of Kirchhoff and Bunsen (*Wiss. Klassiker*, No. 72, p. 71) gives the following account as coming from the latter author who was then, 1895, still living:

"Bunsen had for sometime been engaged in the study of flames as colored by various salts and had used these colors as a means of analysis.

"For the purpose of distinguishing between flames having apparently the same color, he interposed colored glasses and colored solutions—and with considerable success.

"It was during a conversation on this subject that Kirchhoff suggested to him that the different colors in the flame might be more completely separated by means of a prism; later Bunsen was aided by Kirchhoff in carrying out this idea."

This led to their two joint papers, published in *Pogg. Ann.* in 1860 and 1861, where the question is first raised as to whether each element has a fixed and characteristic spectrum of its own, which is independent of the kind of flame in which it is brought to incandescence, and independent of the compound of which the element may be a component.

After examining the spectra of a large number of compounds in which one and the same element appears as a factor, and after employing a variety of heat-sources ranging from the hot oxy-hydrogen flame to the cold flame of sulphur, they conclude that the positions, at least, of the spectral lines, for any of the alkali metals, are not affected by the remainder of the compound in which the metal appears, or by any range of temperature, or by any of the various chemical processes going on in the flame employed.

Upon this experimental foundation, they established the prism as an instrument whose delicacy, for qualitative analysis, is unsurpassed; and in their second paper applied it to the discovery of two new elements, caesium and rubidium.

The peculiar merit of Bunsen in the field of spectroscopy is then that he perfected a simple method which is capable of detecting the presence of an element by the use of quantities vastly smaller than are required by any other known method.

It opened to chemists, therefore, an entirely new field of investigation and one which, as the sequel has proved, is not confined to our own planet or even to the solar system.

Colored flames had been previously studied by Talbot, Herschel, Swan and Miller, but the work of Kirchhoff and Bunsen was needed to convince chemists that the prism was an instrument both reliable and sensitive.

In this connection, it is interesting to note that it is precisely the deviations from the general principle above mentioned, viz., constancy of position for each line, which form the most interesting subjects of present spectroscopic investigations. Among these may be mentioned the difference between the spectra of various salts of any one metal as determined by Mitscherlich, the shift of position due to motion in line of sight, the shift due to pressure at the luminous source.

Since 1889, Bunsen had not been engaged in active teaching. As a matter of course, learned societies sought to honor themselves by heaping upon him memberships, degrees and orders. These, however, ought hardly to be mentioned on the same page with the genuine admiration which his marvelous skill of hand, his wonderful clearness of thought and his marked originality called forth from the scholars and students of two continents. And even this praise can hardly have a place beside the loving esteem which his simple-mindedness and his warmheartedness gained for him among all his personal friends.

THE WAVE-LENGTH OF THE CORONA LINE.

By C. A. Young.

Professor Campbell's note in the October number of this Journal seems to require a word from me, as having been the original author of the apparent misidentification of the corona line with the "1474" line (λ 5317) of the cromosphere spectrum. I am obliged to say frankly, although with some natural regret, that I see no reasonable ground on which to contest the conclusion of Sir Norman Lockyer and Professor Campbell, that the wave-length of the corona line is 5303, and that the line is not identical with the conspicuous chromosphere line at 5317 as I have hitherto supposed. The spectrum photographs which Professor Campbell has kindly sent me appear to be conclusive on this point; and I presume that those of the English spectroscopist are no less so, although I have not yet seen any detailed exhibition of his data such as would enable one to examine them critically.

The explanation given by Professor Campbell to account for the original mistake is doubtless correct, and if the totality had lasted a few seconds longer at the eclipses of 1870 and 1878 I should have detected the error myself. I had planned to set the micrometer wires on the corona line just before the end of totality, and to watch the reappearance of the chromosphere spectrum, followed by the reëstablisment of the ordinary dark line spectrum. Had I succeeded in so doing, the non-coincidence of the corona line with its much more brilliant chromospheric neighbor could not have possibly escaped notice. But on both occasions totality ended prematurely, while I was still searching for other coronal lines in the violet region of the spectrum.

If the weather is favorable next May the eclipse observer will need at the proper moment only a glance to verify or disprove the identity of the corona line with the old "1474."

It is, I think, worth noting that at λ 5303 there is no line of the solar spectrum, either dark or chromospheric; nor, so far as I know at present, is there at that point any line belonging to the spectrum of any terrestrial element yet investigated. The new determination of wave-length frees "Coronium" from all appearance of puzzling affinities or "entangling alliances" with other bodies less exceptional in their character.

PRINCETON, N. J.
Nov. 4, 1899.

DENSITY OF CLOSE DOUBLE STARS.

By Alexander Roberts.

In connection with the theory of the relation of the temperature and density of stars, it is important to put in evidence what is known of the size, mass, or density of celestial gaseous bodies.

The need for such evidence will be manifest when we consider that there is no final certification of the truth of any law, even if we admit its theoretical soundness, so long as it lacks the complete verification that follows from a comparison of theory with the facts deduced from observation.

As regards mass we, of course, can only ascertain this in the case of double stars whose parallax and orbital elements are known. And to determine the density necessitates further a knowledge of the size of the component stars of the system, and this can only be arrived at indirectly by an examination of the light variation of those binary stars whose orbits lie in the same plane as the line of sight.

In the present paper I would seek to deal with the densities of four Algol stars, the light variations of which have been under observation at Lovedale for several years.

The four stars are:

X	Carinae (*Ch.* 3055)	R.A. $8^h\ 29^m\ 8^s$	Dec.$-58°\ 53.2'$ (1900)
S	Velorum (*Ch.* 3416)	R.A. 9 29 27	Dec.$-44\ 45.9$
—	Centauri (*L.* 5861)	R.A. 14 9 55	Dec.$-57\ 23.3$
R S	Sagittarii (*Ch.* 6546)	R.A. 18 10 59	Dec.$-34\ 8.5$

Before dealing with the stars severally it is necessary to indicate the general expressions for the density of any system.

Let us employ the following designations:

Periodic time (in years)	t
Semi-axis major	r
Eccentricity of orbit	e
Diameter of component (1)	pr
Diameter of component (2)	qr

Mass of component (1) - - - - m_1
Mass of component (2) - - - - m_2

Then

$$\text{Density of (1)} = \frac{(0.0092)^3}{p^3\, t^2}\left(\frac{m_1}{m_1 + m_2}\right);$$

$$\text{Density of (2)} = \frac{(0.0092)^3}{q^3\, t^2}\left(\frac{m_2}{m_1 + m_2}\right).$$

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Putting

$$\frac{m_2}{m_1} = k \qquad \frac{m_1}{m_2} = k_1$$

the expressions become,

$$\text{Density of (1)} = \frac{(0.0092)^3}{p^3\, t^2}\left(\frac{1}{1+k}\right); \tag{1}$$

$$\text{Density of (2)} = \frac{(0.0092)^3}{q^3\, t^2}\left(\frac{1}{1+k_1}\right). \tag{2}$$

Now $\frac{1}{1+k}$ and $\frac{1}{1+k_1}$ must always be less than unity, indeed only one of the two expressions can ever approach unity, for as k or $\frac{m_2}{m_1}$ approaches zero, k_1 or $\frac{m_1}{m_2}$ must approach infinity.

We have practically, therefore, a limit in one direction to the density of any system, in the expressions

$$\frac{(0.0092)^3}{p^3\, t^2} \text{ and } \frac{(0.0092)^3}{q^3\, t^2}. \qquad \text{(3) and (4)}$$

The densities of any two stars of a binary system may be very much less; but never can be greater than, or even equal to the values yielded by these expressions.

The quantity t is simply the light period of the variable expressed in years, and p and q are quantities, which, in certain cases, can be determined from an examination of the light variation at minimum phase.

It is evident that in the case where the masses of the two components are nearly equal the densities of either star will be half that yielded by the expressions (3) and (4).

X CARINAE; CH. 3055.

The light variation of this star is extremely regular; the similarity between the increasing and decreasing phases, and the

regularity of the successive minima indicate a more or less circular orbit.

The elements of variation are:

Total period	13 hours
Constant period	6½ "
Descending period	3¼ "
Ascending period	3¼ "

Considering the several minima to be due to the revolution around one another of two stars of equal brightness and equal size, the orbital period of this close binary will be 26 hours.

These data yield the following values:

t	0.0030^y
p	0.71
q	0.71

Substituting in equations (1) and (2),

$$\text{Density of (1)} = 0.25\left(\frac{1}{1+k}\right);$$

$$\text{Density of (2)} = 0.25\left(\frac{1}{1+k_1}\right).$$

If we take both stars to be of equal mass then the density of either component is equal to

$$0.125$$

or one eighth of the Sun's density.

We have assumed a central eclipse. On any other assumption the density will be less than that just obtained.

S VELORUM; CH. 3416.

I have already in *Astronomical Journal*, No. 327, indicated the nature and theory of the variation of this remarkable Algol star.

Briefly stated the elements of variation are:

Total period	$5^d\ 22^h\ 24^m\ 23^s$
Descending period	4 10 0
Constant period at min.	6 30 0
Ascending period	4 10 0

The normal magnitude of S Velorum is 7.8, and the magnitude at minimum 9.3. During the constant magnitude, 7.8,

we have the combined light of both stars; during the constant period when the magnitude is 9.3 we have only the light of the fainter, but larger companion. That is, the smaller star is four times brighter than the larger.

Assuming a circular orbit for S Velorum we have the following values for a determination of the density:

t - - -	0.01624^y
p (brighter star) -	0.17
q (fainter star) - -	0.46.

From which we obtain

$$\text{Density of brighter star} \ldots 0.61 \left(\frac{1}{1+k}\right);$$

$$\text{Density of fainter star} \ldots . 0.03 \left(\frac{1}{1+k_1}\right);$$

or maximum limit of density,

Bright star - - -	0.61
Faint star - - -	0.03

The remarkable circumstance about this result is the density of the fainter but larger star. In the case of the smaller star contraction into very much less bulk has evolved four times more light than that emitted by the larger star.

It may be objected to this result that it depends upon an assumed circular orbit.

Considering the orbit as elliptical, and

Eccentricity - - - - - -	e
Angular distance between line of sight and line of apsides - - - - - -	θ

Then

$$\text{Density of bright star} = 0.61 \left(\frac{\sqrt{1-e^2}}{1+e\cos\theta}\right)^3;$$

$$\text{Density of faint star} = 0.31 \left(\frac{\sqrt{1-e^2}}{1+e\cos\theta}\right)^3.$$

The relation between the diameters of the stars and the axis-major of the orbit precludes a higher eccentricity than 0.5, for any greater value would mean collision at periastron passage.

Also it is evident that the greatest value of the density is obtained when $\theta = 180°$.

Considering now the value of the eccentricity to be the greatest possible, 0.5 ; and eclipse to take place at apastron, then the greatest possible values of the densities of the two stars become

Bright star	3.17
Faint star	0.16

That both these values are far too great is certain. They assume a high eccentricity. The regularity of the light curve is directly against this assumption. They assume a value of the mass of either star infinitesimally small.

But with every possible combination of mass, position in orbit and eccentricity, the value of the density of the faint star is still exceedingly small.

— CENTAURI ; LAC. 5861.

The light variation of this star is extremely regular, being capable of representation under a simple trigonometrical form.

Its light changes are accomplished in $7^h\ 16^m$. Considering the variation to be due to the revolution of two stars of equal brightness, around one another, this means an orbital period of $14^h\ 32^m$, in which time two maxima and two minima take place.

From the absence of any stationary period at either the maximum or minimum epoch, it would appear that the two stars revolve around one another almost in contact.

Although it is impossible to grant under these conditions a spheroidal shape to either star, still the departure from this figure will not be so great as to vitiate the following results.

l	0.0017^y
p	1.0
q	1.0

from which we obtain as the density of the two components of — Centauri.

First star . . . . . $0.27\left(\frac{1}{1+k}\right)$;

Second star . . . $0.27\left(\frac{1}{1+k_1}\right)$.

Assuming the masses of the two stars to be equal we have as the maximum possible value of density of either star,

0.14.

This result is based on the assumption of a central eclipse; any other assumption will only diminish this quantity.

R S SAGITTARII; CH. 6546.

A full investigation of the orbital elements of this remarkable Algol variable is given in *A. J.*, No. 373.

More extended observations have only slightly modified the conclusions reached in that paper.

The form of the light curve is extremely regular, the elements of variation being

Full period	2^d	9^h	58.6^m
Duration of Chief Min.		10	40.
Duration of Secondary Min.		7	0.

Secondary minimum takes place almost midway between two chief minima.

From these data we obtain the following values:

Periodic time	0.0066^y
Eccentricity	0.25
p	0.48
q	0.44

The larger of the two stars is twice brighter than its smaller companion.

The values just given yield the following densities:

$$\text{Bright star} \ldots 0.16\left(\frac{1}{1+k}\right);$$

$$\text{Faint star} \ldots 0.21\left(\frac{1}{1+k_1}\right).$$

As already indicated $\frac{1}{1+k}$ and $\frac{1}{1+k_1}$ must under any relative condition of mass be less than unity, so that 0.16 and 0.21 represent the greatest possible densities of the two stars which make up R S Sagittarii.

In the case of the masses of the two stars being nearly equal, these values will be reduced one half.

GENERAL RESULTS.

It will be sufficiently apparent that a definite determination of the density of any one of the stars discussed in this paper is an impossibility in the present state of our knowledge; we must content ourselves with being able to indicate a limit in one direction to the values sought. Precise values cannot be secured so long as the inclination of the orbit and the relative masses of the two components remain unknown.

Gathering the results together we find for the densities

X Carinae	0.25	and	0.25
S Velorum	0.61	"	0.03
— Centauri	0.27	"	0.27
R S Sagittarii	0.21	"	0.16

These are absolute maximum values of the density of the stars dealt with, assuming in the case of S Velorum a circular orbit, an assumption in keeping with the facts of variation.

We may push the investigation one step further and deduce the mean average densities of all the stars, and in this case it will be sufficient to consider k and k_1 equal; their inequality will have very little effect on the average of all the values.

The average density of the four systems dealt with in the foregoing paper is

0.13.

That is, the average density of a close Algol variable is only one eighth that of the Sun.

This result is sufficiently striking, but it is in no way new. The low density of close double stars has been indicated by more than one astronomer. Any value which the preceding investigation has does not depend upon its novelty but on its relation to the laws connecting stellar temperatures and densities. And it is as a contribution to any discussion which may arise as to the validity or application of such laws that the investigation is offered.

LOVEDALE, S. Africa
April 1899.

THE DENSITIES OF THE VARIABLE STARS OF THE ALGOL TYPE.

By HENRY NORRIS RUSSELL.

IT is possible in the case of an Algol-star, assuming the eclipse theory of its variation, and a circular orbit, to deduce a limiting value for its mean density from its period and the duration of its light-variation, any uncertainty as to the result being due to the uncertainty in the ratio between these two quantities, which is, as a rule, not yet very accurately determined,

Let r be the radius of the bright component, r' that of the dark, and a the radius of the orbit. Let t be the period, and d the duration of the light-variation, that is, of the eclipse, and let m be the total mass of the system.

The mean density ρ' of the system is the quotient of its mass by its total volume; that is

$$\rho = \frac{m}{\frac{4}{3}\pi(r^3 + r'^3)}. \tag{1}$$

Now
$$r^3 + r'^3 \geq \frac{1}{4}(r + r')^3, \tag{2}$$

the sign of equality holding only when $r = r'$.

When the eclipse begins or ends, the disks of the two stars are apparently tangent, and the distance of the projections of their centers upon a plane perpendicular to the line of sight is $r + r'$. Between the beginning and middle of the eclipse the stars move through an arc of their orbit equal to $\frac{\pi d}{t}$, and the relative displacement of their projections is $a \sin \frac{\pi d}{t}$. But this displacement is equal to the projection of the distance of their centers at first contact upon the line of relative motion. Therefore

$$r + r' \geq a \sin \frac{\pi d}{t}, \tag{3}$$

the sign of equality holding only when the transit is central.

We have also

$$m = K\frac{a^3}{t^2} \tag{4}$$

where k is a constant depending on the system of units used.

Combining (1), (2), (3) and (4) we have

$$\rho \leq \frac{3K}{\pi t^2 \sin^3 \frac{\pi d}{t}} \tag{5}$$

where the sign of equality is to be used only in the case of a central eclipse of equal stars. This formula gives a superior limit for the mean density of the system independent of its dimensions.

It remains to determine the constant $\frac{3K}{\pi}$. The period of a particle revolving close to the Earth's surface is 1.411 hours. That of two Earths revolving just out of contact would be twice this. The eclipse of one of these bodies by the other would occupy half the period.

The sign of equality may in this case be used in formula (5) and, taking the Earth's density at 5.53, we obtain $\frac{3K}{\pi} = 44.1$ where the unit of time is one hour, and the unit of density that of water.

The results of the application of the formula (5) to the seventeen known Algol-variables are given in the following table :

No. in Chandler's Catalogue	Name	t in hours	d in hours	Limit of density
320	U Cephei	59.82	10.	0.098
1090	β Persei	68.81	9.15	0.139
1411	λ Tauri	94.87	10.	0.142
2610	R Canis Maj.	27.26	5.	0.366
3055	X Carinae[1]	13.00	6.5	0.261
3109	S Cancri	227.63	21.5	0.035
3416	S Velorum	142.40	15.2	0.061
5374	δ Librae	55.85	12.	0.058
5484	U Coronae	82.85	9.75	0.137
5949	R Arae	106.21	10.3	0.145
6189	U Ophiuchi	20.13	5.1	0.298
6442	Z Herculis[2]*	95.82	5.3	0.728
6546	RS Sagittarii[3]*	57.98	10.4	0.086
7399	W Delphini[4]	115.35	10.	0.170
7488	Y Cygni*	71.90	8.	0.212
	DM.+12° 3557[5]	21.35	5.	0.320
	B.D.+45° 3062[6]	109.75	13.	0.076

The data are those of Chandler's *Third Catalogue of Variable Stars*, except as noted.

It is possible that the gradual change of brightness near the beginning and end of the light oscillation is produced by some other cause than the interposition of an opaque body. If this is true, the tabulated values of d are greater than the true intervals between the contacts at eclipse, and the calculated limits of density are consequently too small. In the case of Algol, Vogel[7] concludes that the real duration of eclipse is about 6½ hours, and so finds a density about twice as great as the limit found in this article upon the assumption of an eclipse lasting 9.15 hours.

Since it is improbable that the orbits of these systems are actually circular, the numerical values in the table are only rough approximations to the truth. An eclipse near periastron would occupy less time than if the orbit were circular, and the calculated limit of density would be too great. The reverse

* Secondary minima.

[1] ROBERTS, *A. J.*, 383.

[2] DUNÉR, this JOURNAL, **1**, 285.

[3] ROBERTS, *A. J.*, 373.

[4] *Harvard Observatory Circular* No. 5.

[5] SAWYER, *A. J.*, 450.

[6] CERASKI, *A. N.*, 3572.

[7] *A. N.*, 2947.

would be the case at apastron, since the computed limit of density varies as the cube of the relative velocities of the stars.

Since in an elliptical orbit the velocity is greater than in a circular orbit of the same period for more than half its circumference, and since the velocity at periastron is increased above the normal in a greater ratio than it is diminished at apastron, the mean value of the limit of density computed by formula (5) for a considerable number of stars would be increased by the effects of eccentricity above its true value.

The stars Z Herculis, Y Cygni and R S Sagittarii have secondary minima. By taking the mean of the durations of the two minima — as has been done in the table — the eccentricity is nearly eliminated, and since Dunèr[1] and Roberts[2] have shown that in these systems the components are almost equal in size, and the transits almost central, the limits of density given above are probably close to the true values.

Notwithstanding the causes of uncertainty, it is evident that the Algol-variables as a class are much less dense than the Sun, probably less than one fourth as dense. If these stars consist of a nucleus and an extensive luminous atmosphere, the nuclei may, of course, be much denser.

PRINCETON UNIVERSITY,
October 9, 1899.

[1] This JOURNAL, 1, 285. *A. J.*, 265.

[2] *A. J.*, 373.

NOTE ON THE SPECTRUM OF P CYGNI.

By A. BÉLOPOLSKY.

I HAVE very recently obtained several spectrograms of the well-known star P Cygni (mag. 5.0) with our two-prism spectrograph, to which a camera of only 250 mm focus was attached. The spectrum extends from F to $H\gamma$, and the plates show the comparison lines of *H*, *Fe*, *Sn*, and *N* (air lines). As is well known, the lines in the spectrum of this star are both dark and bright; this is particularly the case on my plates for the *He* line at λ 4472 and for the hydrogen lines. The bright lines are about in coincidence with the artificial lines, while the dark lines are sharp (particularly λ 4472) and strongly displaced toward the violet end of the spectrum.

But my attention was especially struck by the fact that a dark and bright line correspond in the star's spectrum to each of the comparison air lines of the group from λ 460 $\mu\mu$ to 465 $\mu\mu$, with possibly one exception. The bright lines are faint and not measurable, but they nearly coincide in position with the artificial lines. The dark lines are displaced toward the violet. I give in the following table the wave-lengths reduced by Hartmann's formula of the lines measured on the plate of September 21 and 22, 1899. Column *B* gives the bright lines, *D* the dark lines, *C* the artificial comparison lines, and *S* the wave-lengths, according to Rowland, Runge, and Neovius.[1]

A repetition of the measurements of the differences between the comparison lines and the dark lines of the group λ 4607 to 4651 gave these results:

λ	Difference	
	Revs.	Tenth-meters
4607	— 0.185	— 1.56
4622	— 0.145	— 1.22
4631	— 0.188	— 1.58
4642	— 0.175	— 1.48
4651	— 0.133	— 1.12

[1] "Om skiljandet af Kväpvets och syvets linier." Stockholm, 1891.

P CYGNI. SEPTEMBER 21 AND 22, 1899.

B	*D*	*C*	*S*	*El*	Remarks
		4308.0	4308.0	*Fe*	
		4326.0	4326.0	*Fe*	
4340.8	4338.1	4340.6	4340.7	*Hγ*	Very bright
4345.7	4344.8		4345.4	*O?*	Very fine line
		4383.8	4383.7	*Fe*	
	4386.7		4388.1	*He*	
4396.1					
		4404.9	4404.9	*Fe*	
4420.1					
4472.1	4469.6		4471.8	*He*	Brightest line of all
		4525.0		*Sn*	
	4551.7		4552.6	*N?*	
	4561.7				
4601.9		4601.5	4601.3	*N*	
	4606.2	4607.2	4607.2	*N*	
		4613.9	4614.2	*N*	
	4620.3	4621.5	4622.0	*N*	
4631.5	4629.2	4630.8	4630.9	*N*	Strongest of the air lines
	4640.8	4642.7	4640.5 4643.4	*N*	Comparison line double
	4648.3	4649.2	4651.0	*N*	O : λ=4649.2 ; Fe : λ=4647.6
4713.5	4711.0		4713.3	*He*	
4861.6	4858.2	4861.5	4861.5	*Hβ*	Very bright

The corresponding differences for the hydrogen lines appear somewhat greater: for F — 3.4, and for *Hγ* 2.7 tenth-meters. This is certainly to be explained by silver precipitation of the bright lines overlying the dark lines at their edges, so that the observer makes his settings on the edge of the bright line, and not on the dark line.

No noteworthy changes from the above plate occur on the seven spectrograms of the star which I obtained between September 21 and October 1.

PULKOWA,
October 1899.

APPARATUS AND METHOD FOR THE PHOTOGRAPHIC MEASUREMENT OF THE BRIGHTNESS OF SURFACES.[1]

By J. HARTMANN.

ON a photographic plate which has been properly exposed and developed, the blackening of the different portions of the picture corresponds directly to the photographic brightness of those points of the object photographed (the phenomenon of solarization being left out of account), and we may therefore conclude as to the brightness of the object from the degree of blackening. In order to carry out such photographic determinations of brightness in a precise manner the following points must be considered. We shall here always understand the brightness of an object to be the sum of those rays of light effective on the plate employed, which, after leaving the object and passing through the intervening media, actually reach the sensitive film. In each case it will be necessary to determine by special investigation to what extent the rays emitted by the object, for which the plate in question is sensitive, are lost by absorption in the air, as well as in the lenses and other optical parts of the photographic apparatus, which will depend upon the arrangement of the experiment. This definition of the photographic brightness corresponds exactly to that of the optical brightness as measured with ordinary photometers. For also in the case of optical measurements the intensity is determined of only those rays which actually pass from the source to the eye of the observer, and for which this eye is also sensitive. We should therefore expect differences in the determination of intensity between the eyes of different observers, as well as between different kinds of plates, particularly in the case of differently colored surfaces, and only measurements with the spectral photometer, whether they are made visually or photographically, are independent of this subjective definition of brightness.

[1] *Zeitschrift für Instrumentenkunde*, **19**, April 1899.

The first difference in principle between the photographic and the optical method arises from the property of the photographic plate that its blackening does not depend solely upon the intensity of the light falling upon it, but also in an equal degree upon the duration of exposure, upon the sensitiveness of the film, and upon the mode of development. It is true that within certain limits the correctness of the Bunsen-Roscoe law, according to which the blackening is proportional to the product of the intensity and the duration of exposure, has been also proven for bromide of silver gelatine plates. A law true only for special cases, the validity of which must first be proven by photometric measurements, cannot, however, be made the basis of such measurements, and for this reason photometric methods should be discarded which employ the different exposures of different parts of the photographic plate as a measure of brightness. For the determination of *light intensities*, use should not be made of rotating disks, with sectors of different sizes cut out of them, which are very suitable for sensitometer comparisons, in which the question is the determination of those *exposures* which produce equal blackening on different plates.

The only principle which can be made the basis of a photographic-photometric method, free from unnecessary assumptions, is this: Two sources of light are photographically equally bright when they produce equal blackening on one and the same plate with equal exposures.

We assume here only that every plate has the same sensitiveness over its whole surface, and that the development, and other treatment of the plate, have been precisely the same for all different points. If we should not make these two assumptions, the photometric utilization of photographic plates would be entirely impossible.

If any source L is to be compared with a standard lamp N, a portion of the plate is illuminated by L for a definite time from an accurately measured distance; at a neighboring point on the plate the scale is produced, the separate fields of which are obtained by precisely the same exposure at different distances

from the standard lamp. It therefore only remains to determine to which field of the scale the blackening produced by the source *L* corresponds, in order to calculate accurately, according to the fundamental law of photometry, the brightness of *L* expressed in units of the standard lamp. In exactly the same way the separate parts of a picture taken with any kind of photographic apparatus can be measured photometrically by a normal scale produced on the same plate, but it is to be remarked here that the brightness of the picture thus found is not to be immediately considered as the brightness of the object, as mentioned above.

The process here given makes it possible to measure photometrically whatever can be obtained photographically; in particlar, objects can be rapidly measured in this way which have hitherto escaped direct photometric observation on account of their faintness, their rapid changes, or other reasons. I will only recall how laborious any accurate comparison of the brightness of the different formations of the Moon's surface has been hitherto, on account of the constantly changing illumination, while on a photograph of the Moon, which can be obtained in a second, the instantaneous distribution of light can be preserved and afterwards measured with great accuracy, at as many points on the image as may be desired. Similarly the brightness of comets and nebulae is easily determined in this way.

The observation proper in this photometric method lies in the comparison of the picture with the fields of the scale which are found on the same plate. In sensitometer measurements such a comparison has to be made, but then the two exposed places are on two different plates. Hitherto this observation has commonly been obtained by placing the scale near that portion of the plate where the blackening is to be measured (by cutting the plate if necessary), and then estimating to which step of the scale the blackening corresponds. This process, however, is neither very reliable nor always applicable. If the place which is to be measured lies between regions of different degrees of blackening, or if the plate cannot be cut, then the scale cannot

be brought sufficiently near, so that the estimation becomes very uncertain. Even when it is possible to bring into contact the two fields which are to be compared the process is not wholly

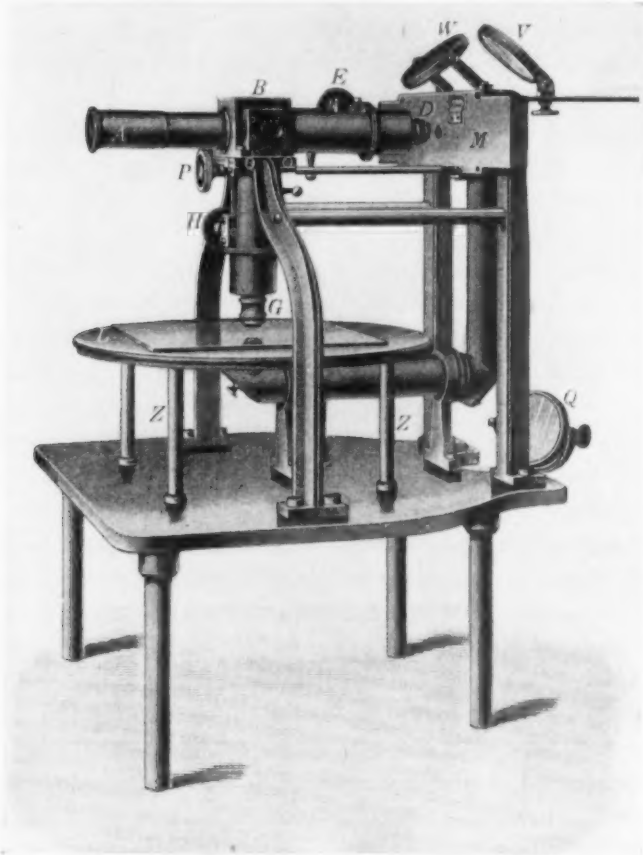


FIG. 1.

free from objection, since a peculiar optical phenomenon complicates the precise estimate of the blackening. On all scales which consist of a series of fields of different blackening, in close succession, each field will appear to be shaded off, and is the darker the nearer it comes to the neighboring brighter field, although

the blackening within each field is known to be perfectly uniform from the mode of their production. The boundary of this neighboring field may be recognized as a line of especial darkness. It follows from this that in judging the brightness of surfaces the eye is in a high degree influenced by the brightness of the adjoining surfaces. In the exact measurement of surface brightness it is therefore essential that the area to be observed is entirely isolated from its surroundings.

These were the guiding principles in the construction of the apparatus described below, which may be designated as a microphotometer, since it is a combination of microscope and photometer. The apparatus was built for the Astrophysical Observatory by O. Toepfer, of Potsdam, in an admirable manner, and is intended to be used for the photographic measurement of the surface brightness of celestial bodies and their spectra.

Fig. 1 gives a perspective view of the instrument, and Fig. 2 a vertical section. A round table of 25 cm diameter is supported by four posts *Z*, parallel to a horizontal base plate *U U'*. Its surface *L*, is covered by a dull black plate of ebonite, and it is sufficiently large so that the edges of large plates can be brought over the aperture in the middle of the plate without the necessity of fastening the plate. Vertically above the aperture is situated the objective of a broken microscope *A B G*, the optical parts of which are so calculated that the sharp image of the granulations of the plate can be thrown in the middle of the base of the rectangular reflecting prism *B*, on adjusting the objective by the rack and pinion *H*. The magnifying power is 12.

The prism has the arrangement proposed by Lummer and Brodhun,[1] which may be seen more clearly in Fig. 3. To the base *a b* of the prism *B* a second precisely similar prism *C* is cemented in such a way that reflection can only occur at the small portion *g h*, while all about this portion the rays pass unhindered from one prism to the other. This is accomplished either by making a slight depression in the middle of the base of the prism *C* before cementing or, more simply, by first silvering the portion

[1] *Zeitschrift für Instrumentenkunde*, 9, 41, 1889.

selected on the base of *B* and then cementing the prisms. It is possible to look directly through the cube thus produced in the direction *A B D* (Figs. 1 and 2), while the rays coming from *G* are seen in the small mirror in the middle. The form and size

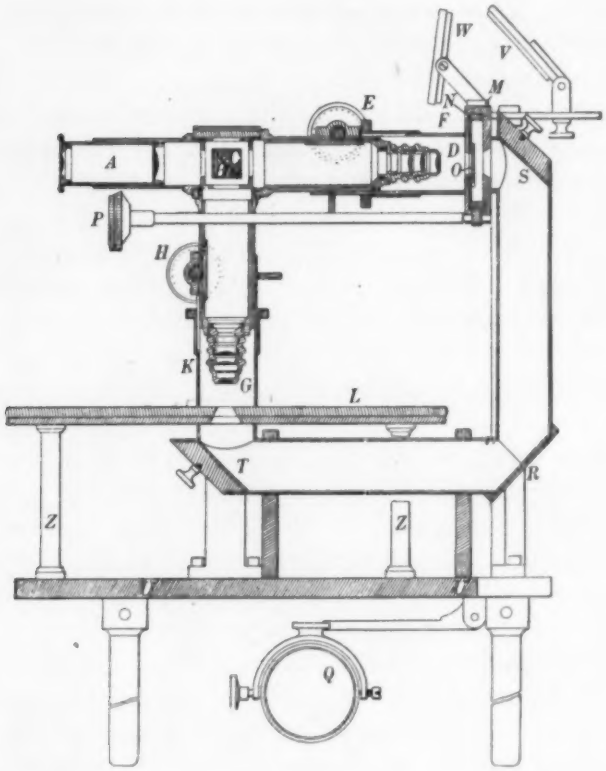


FIG. 2.

of this mirror will be governed by the nature of the object to be measured, and various combinations of prisms can be furnished with the apparatus. If circular regions are to be observed on the plate under investigation, the mirror will have the form of an ellipse, the major axis of which, lying in the direction of *g h*, is in the ratio of 2 : 1 to the minor axis; the sides of the

rectangular aperture should be given the same ratio if squares are to be measured on the plate. The apparatus furnished the Astrophysical Observatory permits the measurement of the blackening of regions of precisely circular shape and having a diameter of 0.12mm.

A second microscope objective precisely similar to *G* is placed at *D* and can be so focused by the pinion *E*, on the film of the plate situated at *O* (Fig. 2), that this image also falls at the middle of the double prism. On looking into the eyepiece *A* there will be seen in the middle of the field of view a small portion of the plate lying on the table *L*, while the remainder of the field of view is filled by the plate *O*.

The plate *O* is the measuring part proper, and may be designated as a photometer wedge produced photographically. It is 90mm long and 20mm wide, and in the direction of its length the film is given a blackening which increases as uniformly as possible. The construction of this wedge, to be made on the same kind of plate as the plate to be measured, if possible, can be accomplished in different ways, as by illumination behind a rotating disk, from which portions bounded by spirals have been cut out; or in a region of penumbra; or by the uniform withdrawal of the cover from in front of the plate during its exposure; or by copying another similar wedge. The law of the increase of the blackening in the wedge is practically a matter of indifference, but there must be no irregular jumps.

The wedge is fastened in the slide *N* (Fig. 2), which can be moved in the frame *M*, perpendicularly to the axis of the microscope by the pinion *P*. The position of the slide in the frame can be read on a millimeter graduation with vernier, which is illuminated by the two mirrors *V* and *W* and is situated at the distance of distinct vision for the observer at the eyepiece. The wedge is fastened in the slide by means of two stops perpendicular to each other and by springs. It can be reversed at will, which is important for the elimination of certain errors, or can be exchanged for another wedge. The film side of the plate is of course always toward the microscope objective.

In the construction of the apparatus particular attention was paid to the equal illumination of the two plates. Measurements can be made either by daylight or by artificial illumination. If diffuse light of the sky is employed, or, for very dense blackening, direct sunlight, the rays are thrown perpendicularly on the ground-glass plate R, by the mirror Q,[1] which may be turned at will, and pass from R after emerging in both directions at an angle of 45°, through closed tubes to the plane mirrors S and T which then give vertical illumination to the two photographic plates. In place of the mirror Q a lamp may be placed so as to throw its light perpendicularly on the plate R; this form of illumination has proved most satisfactory in my measurements. Variations in the brightness of the source of light have no effect whatever on the measurements, but nevertheless precautions should be taken that the direction from which the plate R is illuminated is not changed during a series of measurements — which may easily occur with the employment of direct sunshine.

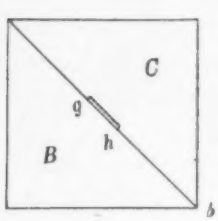


Fig. 3.

The mirrors S and T can be readily removed from the tubes for cleaning. In order to avoid all diffuse light the sliding tubes F and K are attached around the objective ends of the microscope. F is brought into contact with the frame M, and K is moved to within a few tenths of a millimeter from the plate to be measured.

As appears from the above description, the path of light from the ground-glass disk R to the eyepiece is completely enclosed and precisely similar for the two microscopes. In spite of this equality of the two optical systems, the apparatus is not intended to serve for the direct comparison of two blackened portions, but the two portions to be compared are successively brought under the microscope objective G, on the horizontal table, and

[1] The mirror then takes the position shown in Fig. 1. When lamplight is used the arm carrying the mirror is turned about the joint at U', so that Q comes into position under the base plate, as given in Fig. 2.

compared with the wedge. In this way the result is attained that the two surfaces to be compared are observed under perfectly identical conditions.

The measurements with this apparatus are accordingly made in the following manner: after an appropriate wedge has been placed in the slide and the illumination regulated so that the ground-glass disk *R* is perpendicularly illuminated, the observer first focuses the eyepiece sharply on the edge of the small mirror in the double prism, draws the tube *F* out to the frame *M*, and focuses on the grain of the wedge with the pinion *E*. The plate to be measured is then laid upon the table, and the observer focuses upon it with the pinion *H* and slides the tube *K* close up to the plate. The measurements can then begin. The plate is then moved upon the table in such a way that the first field of the scale on the plate appears in the small mirror, and the wedge is moved by turning the head *P* until this place in the middle of the prism has exactly the same appearance as its surroundings. The equalization of the two surfaces can be accurately accomplished and sharply determined, since the dividing line disappears entirely at the correct setting. The setting of the scale is then read off and the next field of the scale is taken up. A series of measurements thus obtained then furnishes a table of the settings of the wedge which correspond to the several fields of the scale and accordingly to the known brightnesses of this plate. After this the picture taken on the plate is measured in the same way and the readings of the wedge thus obtained serve for interpolating from the table the brightness corresponding to the degree of blackening in units of the lamp employed.

I have only to refer to another attachment intended both for rapidly finding the place to be observed in the picture and for making a preliminary test of the plate. If the area of blackening which is to be measured is very small and situated in an irregular area of different brightness, it would be difficult to set the desired portion of the plate exactly at the reflecting surface in the middle of the prism, since all of the surrounding

parts of the plate cannot be seen in the eyepiece, so that the orientation is entirely lost. In order to render possible a rapid and exact setting of the desired object in this case, the double prism *B C* can be removed by pressure on a button, and in its place a simple reflecting prism, similar to *B*, can be brought up, which permits the greater part of the plate to be seen. A curve drawn on the base of this prism and corresponding to the outline of the reflecting surface in the double prism then bounds that part of the plate in the field of view which alone can be observed after replacing the double prism. The simple prism and double prism are attached beside each other in a slide which can be moved back and forth between stops, so that a change of prisms can be made in less than a second. In Fig. 1 the slide may be seen pushed out to its right hand stop.

In the form thus described the apparatus serves for the direct comparison of the density of the silver precipitation, since the magnification employed clearly shows the grain of the more sensitive bromide of silver plates. If the grain of the two plates to be compared is very different, however, as may be the case in sensitometer measurements, it is better to compare the transparency of the two plates. For this purpose we may either screw on in place of the objectives *D* and *G*, two equal diaphragms furnished with the apparatus, which may be brought close to the film, as is sufficient in many cases, or we may disturb the focus by the pinions *E H* until the grain disappears. Measurement with a sharp focus is to be preferred in general, since it is here easy to recognize with the use of the small prism, whether the area focused upon is uniformly blackened or whether its transparency is affected by specks or holes in the film.

Measurements can be made with extreme rapidity and ease with this apparatus, and I beg to give an example of their accuracy.

Each of three observers made ten settings on one and the same portion of a scale and obtained the following readings of the setting of the wedge.

Observers:	Müller	Kempf	Hartmann
	37.8 mm	37.6 mm	37.7 mm
	37.7	37.5	37.7
	37.9	37.4	37.4
	37.4	37.4	37.7
	37.4	37.4	37.8
	37.4	37.6	37.6
	37.4	37.5	37.7
	37.8	37.6	37.6
	37.6	37.6	37.7
	37.7	37.8	37.7
Mean	37.61	37.54	37.66

In order to determine to what range of brightness the displacement of the wedge by 1 mm corresponds at the portion here used, the two neighboring fields of the scale, the coefficients of absorption of which had been previously determined, were also compared, with the following result:

Setting of wedge	Log I	C
40.50 mm	—0.534	
37.66	—0.632	—0.035
35.10	—0.728	—0.038

Log I is the logarithm of the quantity of light transmitted by the particular portion of the scale, the quantity of incident light being called unity. C is the range of log I for displacement of the wedge by 1 mm. If we place $C = -0.0365$ as a mean value, for the portion of the wedge used above, 1 mm of the wedge will here correspond to a range of brightness of 8.77 per cent., or, expressed astronomically, to 0.091 magnitudes.

The differences between the above results of the three observers are accordingly:

M.—K.	+0.07 mm	0.61%	0.0064 magnitudes
K.—H.	−0.12	1.05	0.0109
H.—M.	+0.05	0.44	0.0046

The largest difference occurring between two settings by a single observer was:

for M.	0.5 mm	4.4%	0.046 magnitudes
K.	0.4	3.5	0.036
H.	0.4	3.5	0.036

while for the probable error of a single setting of the wedge the following figures are obtained:

for M.	0.133 mm	1.17%	0.012 magnitudes
K.	0.085	0.75	0.008
H.	0.072	0.63	0.007

Further measures will be elsewhere published.

KGL. ASTROPHYSIKALISCHES OBSERVATORIUM,
Potsdam.

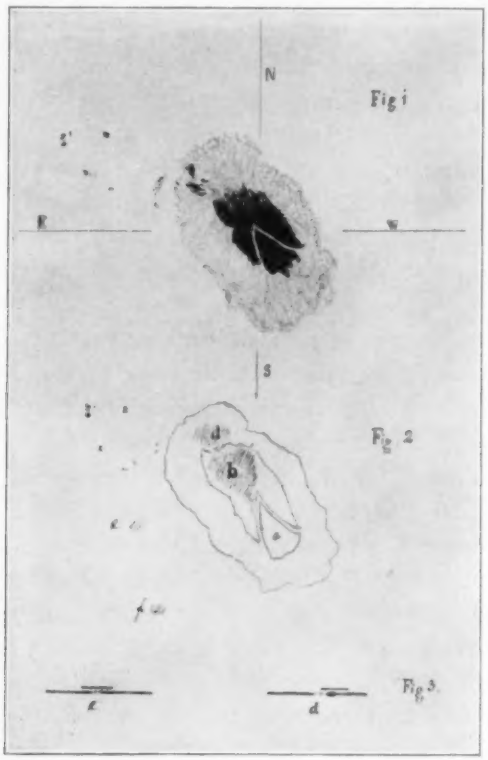
THE GREAT SUN-SPOT OF SEPTEMBER 1898.

By J. FÉNYI, S. J.

THIS phenomenon, remarkable enough on account of its enormous size, receives a special significance from the very unusual aurora which accompanied it. Even at Kalocsa, in latitude $+46^\circ\ 32'$ and longitude $18^\circ 58'$ east of Greenwich, the aurora was observed for about a quarter of an hour at 9^h Gr. M. T. on September 9. An aurora is here an almost unheard of occurrence, one like this not having been seen in this section, even at a solar maximum, since 1872. It therefore does not seem superfluous to communicate the observations of the spot made at Kalocsa.

I made drawings of the spot on twelve days of its transit. The accompanying drawing was at 10 A.M. Gr. M. T. on September 5, with the helioscope attached to the 4½-inch telescope. From the whole number of observations with projection apparatus I determined the heliographic longitude as 241.7°, and the latitude as —12.5°. According to these determinations the spot passed around the east limb of the disk on September 2 at 8^h A. M.; when I made the regular observations of spots with the projection apparatus at $1^h\ 45^m$ the spot was not yet visible, but as I showed the Sun to a visitor at $3^h\ 45^m$ the strong dark line on the eastern edge at once attracted attention. According to computation the spot was then at a distance of 3.3′ from the edge of the disk, without regarding refraction. I at once applied the spectroscope and now found the place, which at the regular observations at $1^h\ 30^m$ P. M. showed nothing unusual, to be already in an eruptive state. The eruptive line at $\lambda 6677$ was visible for an extent of 11°, and from position angle $119^\circ\ 30'$ to $121^\circ\ 0'$ the chromosphere appeared extremely bright and covered with the familiar flames. This point, however, did not lie over the nucleus of the spot indicated by the dark strip, although very near to it, being about one half degree nearer to

the equator, as I was able to observe directly in the spectroscope with certainty. At the nearest place to the nucleus there appeared a significant displacement of the spectral line toward the red. This was measured at $4^h\ 55^m$ and indicated a recession of 470 km per second. While I was showing all this to my well-



informed visitor, a protuberance rose up at 118°, which was at first also visible in the line λ6677. It was inclined toward the equator at an angle of 60°, thus directed away from the spot region, and at $5^h\ 3^m$ had already attained a height of 128″. Further observations were impossible. At no time, either on September 2 at 2 P. M., or at three observations on the 3d, could I see a prominence over the spot region,—a fact which has

already been reported by others. I find in this only a confirmation of the known fact that quiescent prominences do not occur over areas of spots—which are the scene of transitory eruptive phenomena.

As to the further development of the spot I would only remark that the nucleus made a rotation of about 60° in the positive direction from the 5th to the 12th of September, and that the group did not develop strongly until the 9th. The observations of September 5 seem to me to be of especial significance. Between 11 and 12 and again at 1, I let the spot run over the slit. The *Ha* line was very bright over a portion of the nucleus and out beyond it. I could readily recognize the parts of the nucleus, and sketch the form of the red mass. Fig. 2 is intended to represent the outline of the spot and the parts of the nucleus. The reversed portion is indicated by the shading. This appeared at the same time to be brown in the helioscope, in contrast to the bluish-black color which spot nuclei usually have in my refractor. This reversal of the *Ha* could also be seen beyond the spot at a distance of a few degrees, particularly in the places marked *e* and *f*. The location of the latter were not accurately fixed by measures, but hastily estimated in the field of view by the eye. These two points *e* and *f*, as well as *d*, near the nucleus, exhibited the rare phenomenon of a considerable and regular displacement of the dark *Ha* line on the Sun's disk. The peculiarity of this disturbance is best shown by reproducing the observed forms themselves, as they are given in Fig. 3, with the letters in question designated. The shaded portions denote the bright reversal which occurred simultaneously. If we should seek an explanation of these bright reversals, probably the simplest would be the assumption at these points of violent metallic eruptions, which are known to be extremely luminous, and thus could overpower the photosphere in monochromatic light. At these bright places in fact the dark line was not merely enlarged and broken, but the place was brighter than the surrounding spectrum, especially over the nucleus. We are thus also obliged to transfer the origin of eruption within the

spot to the very bright bridge there, for the reversal did not extend beyond the limits of the spot.

The very remarkable displacement of the dark *Ha* line and its doubling on the solar disk is confirmed by the measurement near *d*, where it corresponded to a recession of 108 km. These peculiar appearances were seen on this day only, from 10^h to 12^h, nothing of the sort being visible on the days following. I find it expressly noted in the observing book that no unusual phenomena and no reversals were visible at three times of observation on September 6th ; on the afternoon of the 9th, the day of the aurora, no reversals were seen; and similarly on the 12th and 14th. The spot disappeared on the 15th, and on the particular point on the Sun's limb could be seen only the bright flames and stripes which as a rule characterize the departure of a region of spots.

The simultaneous occurrence of such extraordinary phenomena of a similar nature at a considerable distance from the spot area justifies the conclusion that the cause and source of these powerful disturbances, as well as the common rotation of the group of spots, are not to be sought in a comparatively shallow layer of the surface, but rather in decided depths of the body of the Sun.

In the course of the year 1899 I have otherwise observed such a reversal on the disk only on March 12 and 14, and then less strongly marked. It was situated over the last spot of the large group then visible. A great magnetic disturbance was also reported at that time on March 14. A close relation between these two phenomena is indicated by the fact that according to the magnetic observations at Stonyhurst only two very large magnetic disturbances have occurred during this year, and that both fell at the time when I observed these extraordinary phenomena over the spots — each time following a few days thereafter. This is also confirmed by the magnetic observations at Pola, which registered at these times the only great disturbances in declination.

HAYNALD OBSERVATORIUM.
June 1899.

A SPECTROSCOPE OF FIXED DEVIATION.[1]

By Ph. Pellin and André Broca.

It is well known that when a ray of light has traversed a prism at minimum deviation its direction, after reflection on a mirror attached to the prism, is independent of its color. This is readily understood when it is remembered that the direction of a ray which has traversed a prism at minimum deviation is the same as if it were reflected from its base. If it is then made to undergo reflection the result will be the same as if the ray were reflected on two mirrors making an angle with each other. The final ray will make with the incident ray an angle double that between the two mirrors.

This principle has frequently been employed in bolometric researches where a definite dispersion and a fixed receiving apparatus were required. To realize these conditions it is only necessary to rotate a system composed of a prism and an attached mirror in order to cause the dispersed radiations, at minimum deviation, to pass in succession over the bolometer.

In this form the apparatus is not suitable for practical use in a spectroscope, for silvered glass mirrors give a bad image and metallic mirrors are soon unfit for use. It is therefore necessary to devise a prism giving total reflection on one of its interior surfaces in such a manner as to realize a fixed deviation without the use of a perishable mirror. It must be shown at the outset that under these conditions the property of fixed deviation for a ray twice refracted at the desired angle is preserved.

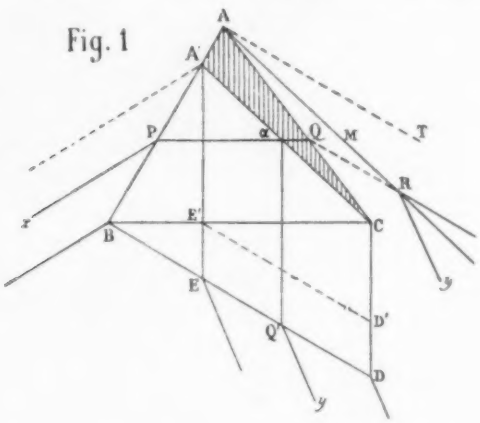
Imagine a prism of 60°, ABC, and a mirror M (Fig. 1). Consider the ray $xPQRy$, and let us endeavor to replace the external reflection M by a total reflection. The emergent ray must take the direction Ry; since we may replace QR by its symmetrical with respect to M, and since we wish to preserve

[1] *Séances de la Société Française de Physique*, No. 1, 1899.

the same angle of refraction Q, we must take as the surface of emergence a surface symmetrical to $A\,C$ with respect to the mirror M. We must therefore take a face parallel to $A\,T$. Under these conditions it is evident that the ray which is twice refracted at the same angle at P and Q' will have precisely the same properties as if it had been refracted at P and Q in the prism $B\,A\,C$.

Let us now consider a 60° prism to be cut by a plane $A'\,G$, such that the angle $B\,C\,A'$ shall be 45°, which gives $B\,A'\,C = 75°$;

Fig. 1



let us join to it a rectangular prism $B\,C\,D$, having acute angles of 30° and 60°, and we shall obtain a prism having an internal reflection and a fixed deviation of 90° which is equivalent to a prism of 60°. It is moreover evident, since the angles $D\,Q'\,y$, $x\,P\,B$ are equal, that the faces $A'\,B$, $B\,D$, must be at right angles.

In the actual construction the faces may be limited to the parts actually used. If we assume an aperture $B\,A'$, we shall obtain a useful prism by joining to $B\,A'\,C$ the prism $E'\,C\,D'$. But this requires the use of cement, which should be avoided if possible. We are thus led to the solution which consists in cutting a single block $B\,A\,C\,D$. This requires a slight increase in the thickness of glass to be traversed, but it avoids the necessity of cementing the surfaces, which is far more important.

Such a prism renders possible the construction of a very

convenient spectroscope. The collimator and observing telescope may be fixed at an angle of 90°. When the prism is rotated the spectral lines will always be at the position of minimum deviation at the moment of crossing the reticule in the telescope. They will thus always be of maximum sharpness.

The operation of setting for minimum deviation of a line is accomplished by a single motion and the fixed position of the telescope simplifies the construction and the use of the instrument. It is only necessary to have a good achromatic objective in order to be able to focus the photographic camera, for example, on the D line, and then, by simply rotating the prism, to bring a given region of the ultra-violet at minimum deviation to the point previously occupied by the D line.

It is evident that the prism just described causes the ray which has traversed it at minimum deviation to turn through an angle of 90° to the right. We will call this prism right-handed. If the same prism worked in the opposite direction, receiving the light on its large face and at a suitable angle, it would be left-handed. Or such a prism may be considered to be reversed top for bottom, in which case the new prism is right-handed when it receives the light on its large face and left-handed in the inverse direction.

The condition of fixed deviation may be met with the greatest simplicity in the construction of a spectroscope having several prisms. It is evident that if we wish to obtain dispersion we must join in pairs prisms which are opposite in character.

Each of these prisms will produce a deviation of 90°, either in one direction or the other, depending upon whether it is made to work in this or that direction. Let us consider the possible solutions for various numbers of prisms.

For a one prism spectroscope either position of the prism may be employed. With two prisms we may obtain either direct vision with displaced path (Fig. 2), or parallelism of the collimator and telescope, as shown in Figs. 3 and 4. With this arrangement the observer is distant only some 20 cm from the slit and source of light. When a telescope of longer focus than

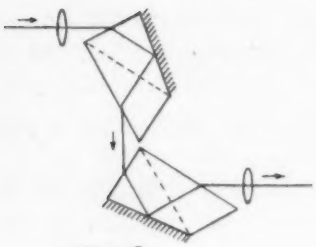


Fig. 2

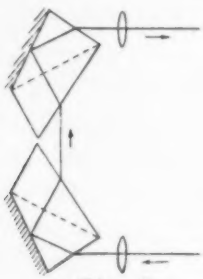


Fig. 3

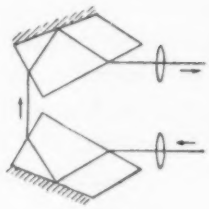


Fig. 4

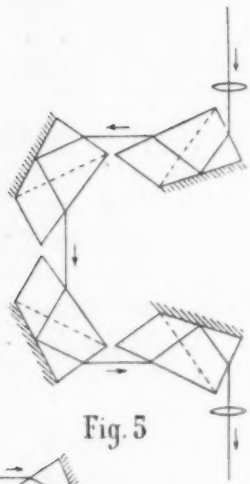


Fig. 5

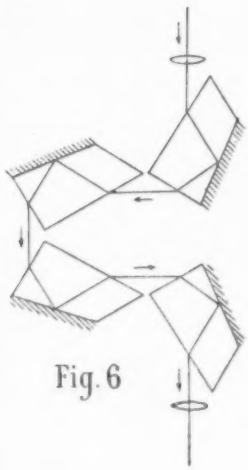


Fig. 6

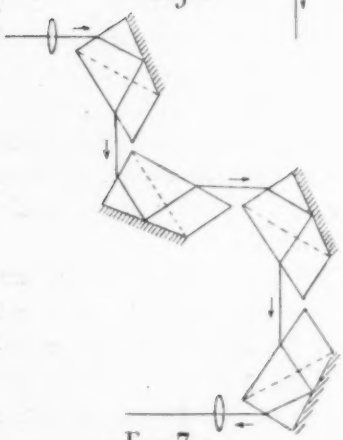


Fig. 7

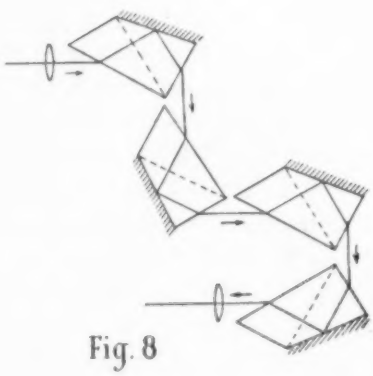


Fig. 8

the collimator is employed, the light source and slit may be placed at any desired distance. In both cases the motions of the prisms are effected by causing them to turn about fixed centers lying upon a perpendicular to the direction of the telescope, by means of two rods moved by a single fixed screw.

If three prisms are used, the collimator and telescope will lie at right angles, either to the right or left. The three prism spectroscope may be of the form (2), (3) or (4). Form (4) is most convenient.

Finally, four prisms may be used, in which case we may have either direct vision (5), or an arrangement like that shown in Fig. 3, with the slit close at hand. For each of these forms there are two solutions, shown in (5), (6), (7), (8).

In all of these solutions, in order to keep the prisms in the required position, it is only necessary to arrange them in such a manner that alternate prisms will rotate in opposite directions. This is easily accomplished by means of a tangent screw having right and left threads, or, in the case where the slit and eye-piece closely adjoin, two right and two left threads. It is evident that the faces of the prisms are always completely utilized.

It is further evident that by setting the telescope in position determined in advance by the aid of a scale, it is possible to observe with $(p-1)$ prisms, if that of order p is removed.

In this instrument a spectral line is defined by the position of the prisms at which it crosses the reticle. The angle through which the spectrum is moved by a rotation a of the prisms is $8a$. The amount of this rotation may be determined with a precision equal to the sensitiveness by means of the image of a micrometer reflected once on each of the refracting prisms. We have realized this by means of total reflection prisms placed above each of the first three refracting prisms. A double total reflection prism brings down the ray so as to utilize as a reflecting surface the last refracting face of the last prism. Thus the observing telescope may be used to measure the rotation. If, moreover, there is any error in the motion of the prism, the readings will be affected in exactly the same way as the displacement of the

spectrum, and a line will always be defined by that division of the micrometer with which it coincides at the desired point.

In arrangements (5) or (7) we may have a motion of the micrometer in the direction of the spectrum, if the rectangular prism giving double total reflection is fixed. If it partakes of the motion of the fourth dispersing prism the motion of the micrometer will be in the opposite direction to that of the spectrum. The pointing of the micrometer wire will not be affected by this; but the system having direct motion is preferable.

Of these instruments we have constructed type (5), which performs perfectly. With the instrument it is possible to make a general examination of a region of the spectrum with a single prism and then to study it in detail with the four prisms. In order to realize the dispersion of eight prisms it is only necessary to employ the principle of auto-collimation, by placing a mirror in the position previously occupied by the collimator.

These instruments seem to be well suited for the use of chemists, as they will permit the use of greater dispersions than are now employed, on account of the possibility of determining positions with a precision of the same order as the dispersion.

RESEARCHES ON THE ARC-SPECTRA OF THE METALS.

V. SPECTRUM OF VANADIUM.[1]

By B. HASSELBERG.

INTRODUCTION.

IN my previous memoirs under the above title I have sought to bring to a temporary conclusion the spectroscopy of the metals nearest to iron. In connection with the spectroscopic researches published in the meantime by Kayser and Runge, and by Rowland, these will satisfy the most pressing necessity in this department of spectroscopy. But more than this they will not do. Only the first step has so far been taken toward the final goal, the complete knowledge of the spectra of the metals, since in spite of all our efforts surely no one of us can cherish the hope of having disentangled more than the principal features of these complicated phenomena. Many peculiarities of a doubtful character in the preceding results will first find their true explanation when similar investigations shall have been carried out for the whole series of the so-called rare metals, which are often widely disseminated, although in limited quantities. An important part of this problem is indeed accomplished in the recent large catalogue of solar spectrum wave-lengths by Rowland; in view of the fact, however, that many of these metals are only meagerly represented in the general solar spectrum, it will not appear unreasonable to undertake this investigation again and to continue it as far as possible.

I was led to give my attention first to vanadium among these metals by the circumstance that Baron Nordenskiold had received a good-sized piece of this metal from Moissan, who had prepared it in the electric furnace, and which Baron Nordenskiold had

[1] *Kongl. Svenska Vetenskaps-Akademiens Handlingar*, Bandet 32, No. 2. Stockholm, 1899.

kindly placed at my disposal. The investigation of the arc-spectrum had already progressed so far that all the measures and reductions were almost ready, when on a comparison of the catalogue of wave-lengths with the titanium spectrum, previously obtained with the use of a Norwegian rutile, several fainter lines in the latter were found, which undoubtedly coincide with the strongest vanadium lines, and hence led to the unexpected discovery of the presence of vanadium in this mineral. This led to the investigation of a whole series of varieties of rutile of different origin, and established the fact elsewhere more fully discussed[1] that vanadium is a common constituent of almost all kinds of rutile. But this also delayed the conclusion of the investigation proper on the vanadium spectrum.

In the meantime a list of lines in the arc-spectrum of this metal, by Rowland and Harrison, appeared in the April number of this JOURNAL, 1898. At first my intention was to at once suppress my own investigations as under the circumstances superfluous, but I later decided otherwise, partly because my measures were almost entirely completed at the appearance of Rowland's catalogue, and partly also because of the fact that my plates contained a considerable number of lines not occurring with Rowland, for the exclusion of which as foreign impurities from my list I did not have, at least provisionally, sufficient justification, while on the other hand several of Rowland's lines were missing on my plates. As I shall show below, I have been able to identify several of these latter lines as easily recognizable impurities, but in general a closer examination of these conditions is difficult, as Rowland gives only the bare list of wave-lengths without any statement whatever as to the elimination of foreign lines. Finally, it seems to me that a comparison of the

[1] This JOURNAL, **6**, 1897. According to a note in this JOURNAL (**6**, 157) Rowland had already observed the presence of vanadium in rutile. However, nothing appears to have been published about it before the appearance of my communications. Furthermore, the occurrence of vanadium in one kind of rutile, that of St. Yrieix, was, as I have recently found, discovered long before us by Sainte-Claire Deville. For this, as well as the wide dissemination of the metal in different minerals, see *Annales de Chimie et de Physique*, **3**, 61, 342, 1861 and W. F. Hillebrand in *Am. Jour. Sci.*, **6**, 209, 1898.

determinations of the lines common to us both, which naturally constitute the great majority, is of no slight interest. In this comparison I have rounded off Rowland's wave-lengths which were expressed to the third place of the Ångström unit to two places, because my value obtained with a plane grating cannot profess a greater accuracy than about two units of this place. On the assumption that the third decimal has a real significance in Rowland's values, which seems to me somewhat doubtful, in view of the diffuseness of the edges often occurring in metallic lines, and their considerable breadth, the greater part of the differences appearing in our measures would fall to me. Nevertheless, even with this limitation, our agreement is throughout very satisfactory, as will be seen from the tables of wave-lengths below.

THE MEASURING APPARATUS.

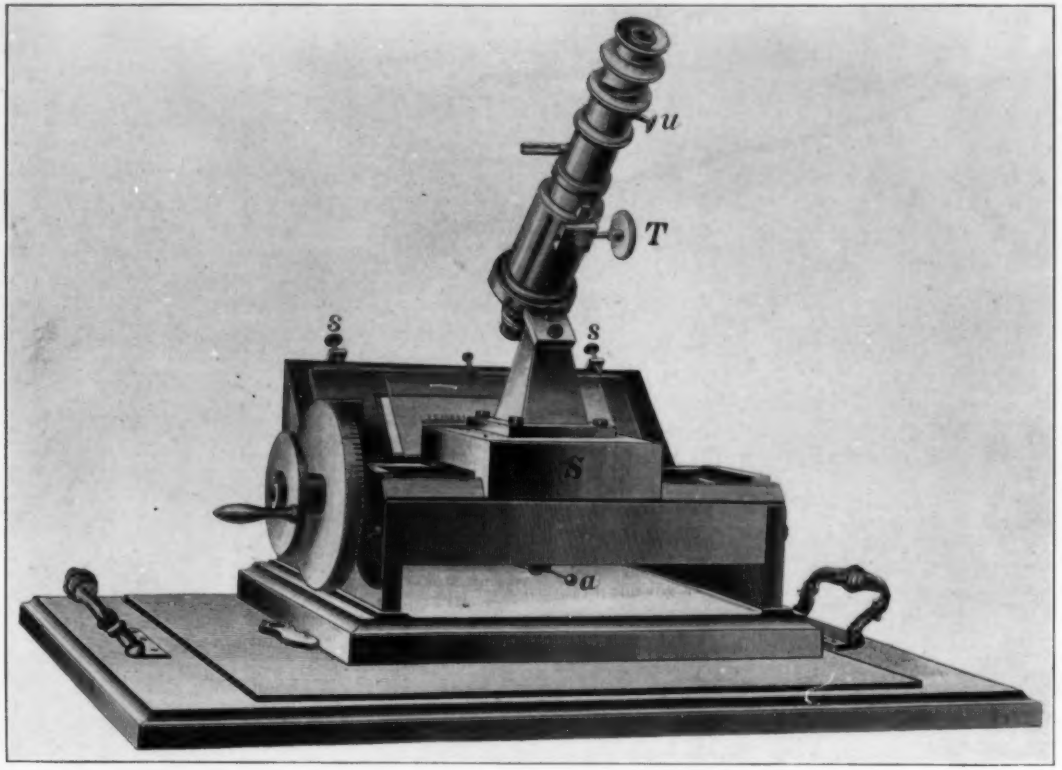
In my previous investigations of metallic spectra I employed an old dividing engine by Perreaux for measuring the negatives. There is nothing to be said against this in respect to the precision obtainable with it, but there is in respect to the convenience of measurement. In this latter respect the vertical position of the microscope wearies the eye very quickly and the unnecessary length of the screw greatly impedes its continuous use. To escape these difficulties I have had a special and very compact measuring machine constructed for the measurement of my spectrum plates, the arrangement of which may be readily seen from the figure (Plate VIII). Two steel rails, the upper one of which is a knife edge and the lower plane, are attached by two brass side-pieces to a strong frame, on which the carriage *S*, with the microscope obliquely attached to it, is moved along by the screw of about 20 cm length bearing in the end-pieces. The end-pieces are prolonged backwards and cut out in such a way that a brass plate with a rectangular aperture can be attached as a support for the photographic plate in such a position that the plane of the latter comes into a position parallel to the screw and perpendicular to the optical axis of the microscope. In order to place the length of the spectrum parallel to the screw the plate is first attached to a strong,

plane-parallel glass disk, which rests upon the brass plate and can be adjusted by means of the two screws *s s* and the spring pressing it against them. In this way the image can be so adjusted that on moving the screw the intersection of the cross hairs of the microscope runs parallel to the edge of the spectrum. One of the threads of the microscope is set parallel to the spectral line by turning the ocular end and clamping by the screw *u*. After the eyepiece has been sharply focused on the cross hairs the final setting on the spectral line is accomplished by moving the whole microscope with the pinion *T*. A small mirror, movable in all directions and serving for the illumination of the plate, is attached to the carriage, and finally by simply releasing the nut from the screw at *a* the carriage can be moved rapidly.

I have employed Bessel's method for the determination of the periodic and progressive errors of the screw. For this purpose the microscope was replaced by another of much higher magnification taken from our Repsold comparator, and then a thread interval in the eyepiece micrometer of the latter of nearly 0.5 revolutions of the screw of the apparatus was measured by successively bringing the two threads into coincidence with a fine line drawn on a cover glass. Starting from each tenth of a revolution the measures were each repeated thrice, and continued through ten successive turns in the middle part of the screw. In this way the following values were obtained for the interval measured:

Turn	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
120—21	0.5138r	0.5132	0.5098	0.5088	0.5067	0.5087	0.5083	0.5115	0.5128	0.5137
21—22	37	22	93	85	65	83	87	105	33	35
22—23	25	35	97	87	72	77	72	095	18	30
23—24	32	32	103	90	77	83	87	090	19	30
24—25	35	23	102	78	80	83	92	113	12	30
25—26	33	33	112	100	75	97	88	095	17	40
26—27	22	25	114	82	73	94	80	084	13	32
27—28	30	22	84	100	80	85	79	079	11	32
28—29	37	36	105	100	80	98	90	111	26	30
29—30	38	31	117	97	88	91	94	097	03	23
Mean	0.51327	0.51291	0.51025	0.50907	0.50757	0.50878	0.50852	0.50984	0.51180	0.51319

PLATE VIII.



PROFESSOR HASSELBERG'S MEASURING MACHINE.

Whence is derived the following correction formula:

$$\Delta u = +\ 0.001365\,\text{r.}\cos u - 0.000248 \sin u + 0.000466 \cos 2u - 0.002927 \sin 2u$$

which, employed at the beginning and end of each measure, leads to the following values of the interval:

Beginning at	0.0	$I = 0.5105$
	0.1	.5110
	0.2	.5106
	0.3	.5104
	0.4	.5101
	0.5	.5115
	0.6	.5104
	0.7	.5102
	0.8	.5105
	0.9	.5107
		0.51059

The comparison is therefore entirely satisfactory. It follows from the table of corrections calculated with the aid of this formula, that the greatest correction for periodic error affecting an interval measured between lines with this portion of the screw does not numerically exceed 0.0065 revs., which introduces a correction of at most 0.008 tenth-meters in difference of wave-length in the spectrum of the third order of my spectrograph, where a revolution of the screw corresponds to about 1.3 tenth-meters. Since in the measurement of my plates I have not been able to carry the precision further than would correspond to a probable error of $\pm$ 0.02 tenth-meters in the wave-length to be determined, the periodic errors of the screw will be of no significance in the present measures, and it may accordingly be regarded as free from error in this respect.

Nevertheless, in order to check the validity of this assumption and at the same time to obtain a somewhat more reliable opinion as to the construction than was possible from the above investigations of its middle part only, I have carried out similar measures at two other points of the screw, each at a distance of forty revolutions from the middle toward the end. These

measures of the interval were here repeated in each group through only five successive turns, and led to the following values:

	To right of middle	To left of middle
Beginning at 0.0	$I = 0.50736$ revs.	$I = 0.51078$ revs.
0.1	.50236	.51092
0.2	.50036	.51082
0.3	.50184	.51094
0.4	.50542	.51174
0.5	.51246	.51248
0.6	.51752	.51220
0.7	.52032	.51132
0.8	.51838	.51074
0.9	.51390	.51048
Mean	0.50999	0.51124

On comparing these figures with those obtained for the central part it appears that the errors decrease from one end of the screw to the other, and that they must be appreciably greater for the turns toward the right than for the rest. The mean values of the measured intervals, viz.:

To right of middle	$I = 0.50999$ revs.
At middle	0.51052
To left of middle	0.51124

show further that the terms gradually decrease in pitch from right to left. In judging of the screw a more suspicious circumstance is that the phase of the errors changes from one part to another, the position of the maxima and minima of the measured interval not corresponding to the same divisions of the micrometer head in the three series of measures. It becomes therefore impossible to combine all the measures into one system in order to derive a table of errors valid for the whole screw; and considered rigorously it will be necessary either to draw up different tables of errors for the different parts, or to eliminate the periodic errors by repetitions of the measures from several starting points of the head. For this reason, therefore, the screw cannot be considered as of the first class; but since, as already remarked, the errors are too slight to appreciably affect

the measures of the spectral plates, I have for the present decided not to procure a new screw. As to the cause of this peculiar behavior, moreover, it is now hardly possible to speak definitely, but the suspicion does not seem impossible that the screw has been subject to a torsion, either during its construction or as an elastic reaction after tempering.

In order to obtain an idea as to the progressive errors, an interval of the above mentioned thin glass plate of 5 mm, or about 10 revolutions, was measured with the 150 central sections, which were almost exclusively used in the measures of spectra. These measures yielded the following:

Beginning at	0 revs.	$\Delta = 10.0224$r.	
	10	.0235	
	20	.0227	10.0226r.
	30	.0229	
	40	.0226	
	50	.0247	
	60	.0235	
	70	.0242	10.0245
	80	.0248	
	90	.0254	
	100	.0245	
	110	.0261	
	120	.0251	10.0258
	130	.0263	
	140	.0269	

which lead to the following corrections:

f_0	= 0.0000 revs.	f_{80}	= +0.0085 revs.
f_{10}	= + .0020	f_{90}	= + .0081
f_{20}	= + .0029	f_{100}	= + .0071
f_{30}	= + .0046	f_{110}	= + .0070
f_{40}	= + .0059	f_{120}	= + .0053
f_{50}	= + .0077	f_{130}	= + .0046
f_{60}	= + .0074	f_{140}	= + .0027
f_{70}	= + .0083	f_{150}	= + .0002

We see that the pitch of the screw gradually decreases a little from right to left, but at the same time that the corrections of these intervals for progressive errors may be neglected as

entirely vanishing, since the distances measured between lines on the plates commonly amount to only a very few turns. For this reason I have also considered it unnecessary to attempt a sharper determination of the progressive errors by the measurement of numerous intervals on the glass plate.

It appears, first, that numerous exact coincidences occur here, in which the lines in the spectrum of vanadium are very intense but those of titanium weak, and consequently they are without any doubt to be assigned to the first metal. I had no reason, as will be readily admitted, to suspect the presence of this impurity in the Norwegian rutile used by me in obtaining the spectrum of titanium, since at the time of my investigation of titanium the vanadium spectrum was unknown to me, and since, moreover, there was no mention in so comprehensive a work as Dana's *System of Mineralogy*, of the discovery of the metal in a French variety of rutile almost forty years before by Saint Claire Deville. The experience thus gained shows that this variety of rutile also contains vanadium, and that, accordingly, the following lines must be removed from my catalogue of titanium lines, as they belong to vanadium:

λ	i	λ	i	λ	i
3636.05	1	4095.65	1	4384.85	2
3688.19	1	4099.94	1.2	4390.11	2
3692.35	2	4105.31	1.2	4400.74	1.2
3704.84	1	4109.92	1.2	4407.85	1.2
3818.37	2	4115.32	2	4408.39	1.2
3823.03	1	4116.64	1.2	4408.70	1.2
3840.90	2	4128.20	2	4441.86	1.2
3855.99	1.2	4134.60	1.2	4444.41	1.2
4090.73	1	4353.01	1	4594.28	1
4092.83	1.2	4379.40	2		

If we omit further those pairs in the above list whose components are separate and therefore independent of each other, there will remain, as common to vanadium and titanium, the lines:

V		Ti	
λ	i	λ	i
4111.93	4	4111.91	2.3
4799.94	2	4799.95	2.3

The following are to be designated as not certainly separate or possibly due to a third metal:

V		Ti	
λ	i	λ	i
3844.88	1.2	3844.87	2
3836.20	2—	3836.22	1.2
4515.75	1.2	4515.76	1.2
4798.12	1.2	4798.13	2
4819.22	1.2	4819.20	1.2

In only the second and last pairs does the coincidence appear to be exact. Of the remainder, the line 3836.22 also occurs as a faint line in chromium, and in the investigation of titanium was designated as a possible impurity of these two metals. Since the vanadium line 3836.20 appears separated from the chromium line, as will be shown immediately below, it is probable that this is also independent of the titanium line.

ELIMINATION OF FOREIGN LINES.

Vanadium and iron.—The extraordinary abundance of lines in the spectrum of vanadium, as well as that of iron, led to the anticipation that the number of the actual, or very close, coincidences would be very considerable. Although in the first examination of the vanadium spectrum the simultaneous comparison with plates of iron permitted the separation of all those lines which, judging by the relations of intensity, could be assigned to the latter metal, nevertheless the subsequent comparison with the tables of wave-lengths of Kayser and Runge yielded an unexpected number of approximate coincidences, for which the lines differed in wave-length by less than 0.1 tenth-meter in wave-length. In order to be able to judge as to these pairs of lines with certainty I made as usual double exposures of the two spectra on the same plate, and accurately investigated the position of the components of each pair under the microscope. The following table shows the results of these observations; in this the wave-lengths of Kayser and Runge have been reduced to the later standard of Rowland by the addition of the correction + 0.07 tenth-meter, and for

convenience of comparison their intensities have been reduced to my scale as well as possible.

V λ	V i	Fe λ	Fe i	Remarks
3476.15	2	3476.24	1	Fe lacking
83.91	2.3	83.98	1	
89.63	1	89.56	1	Separated. Fe trace
3493.34	1	3493.44	1	Separated. Fe trace
3504.57	1.2	3504.59	1	Fe lacking
20.18	2	20.21	1	Fe trace. Coin.?
24.38	2+	24.41	2	Probably separated. λV<λ Fe
29.90	2—	29.97	3	Widely separated
43.68	1.2	43.60	1	Fe lacking
53.43	3	53.36	1	
69.11	1.2	69.16	2	Separated. λV<λ Fe
75.26	1	75.29	1	Scarcely separable
78.01	1+	78.10	2	Coin. λ Fe correct? A common impurity?
83.84	1+	83.81	1	Fe line doubtful
92.71	1+	92.68	1	Separated. λV>λ Fe
3593.48	2	3593.53	1	Coin.
3605.75	1.2	3605.69	3	Separated. λVλ>Fe
11.00	1.2	10.93	1	Separated
14.39	1.2	14.33	1	Fe lacking
16.91	1+	16.83	1	Separated. Trace of Fe
20.53	1.2	20.44	1	Fe lacking
21.37	2.3	21.31	1	
38.57	1	38.51	3	Separated. λV>λ Fe
45.77	1.2	45.70	1	Separated
63.73	2.3	63.67	1	Fe lacking
65.30	2	65.40	1	
65.88	1	65.97	1	Separated. λV<λ Fe
83.27	3	83.25	1	Fe lacking
86.40	2	86.47	1	A strong Fe line coincides with V
3687.61	2.3	3687.65	4	Probably separated
3703.71	3.4	3703.75	3	Not separable. V line reversed
08.88	1.2	08.79	1	Separated
22.76	2	22.76	4	Separated. λV>λ Fe
40.38	1.2	40.29	1	Fe lacking
46.02	2	46.02	4	Separated. λV<λ Fe
56.18	1	56.24	1	Separated. λV<λ Fe
61.61	1+	61.59	1	Separated. λV>λ Fe
77.63	1	77.63	2	Separated. λV>λ Fe
78.83	2.3	78.89	1	Probably λV<λ Fe
93.76	2	93.67	1	Separated
3795.12	3.4	3795.20	5	Separated. λV<λ Fe
3806.93	2	3806.91	3.4	Separated. λV<λ Fe
17.98	1.2	17.91	1	Fe lacking
28.66	3.4	28.72	1	
39.53	2	39.45	4	Widely separated
40.56	2.3	40.65	5	Hard to separate. λV<λ Fe. λ Fe too large, should be 0.59
55.50	3	55.52	1	Perhaps separated
56.00	4	56.07	1	Separated. λV<λ Fe
76.21	2.3	76.21	3	Separated. λV>λ Fe. $\Delta\lambda=0.05$
86.36	1	86.45	3.4	Separated. V?
93.03	3	93.07	1	Separated. λV<λ Fe
94.19	2	94.16	2	Separated. λV>λ Fe

V λ	V i	Fe λ	Fe i	Remarks
3898.16	3	3898.12	3.4	Coin.? V line diffuse. V?
3906.89	2	3906.91	2	Coin.
10.01	3	10.02	3	Separated. λV > λ Fe
10.95	2	11.02	2	Separated. λV < λ Fe
14.45	2	14.42	1	Separated. λV > λ Fe
25.36	2+	25.38	1	Fe lacking
41.40	1.2	41.47	2	Widely separated
73.79	2	73.82	3	Separated. λV < λ Fe
97.30	1.2	97.32	1	Fe lacking
3998.87	3	3998.83	1	
4009.94	1	4009.87	3.4	Widely separated
11.45	1+	11.56	1	Separated
15.50	1	15.47	1	Fe lacking
20.69	1	20.61	1	
23.50	2	23.58	1	
31.37	1.2	31.40	1	Fe trace
32.62	1.2	32.61	1	Fe trace
35.77	2	35.83	2	Widely separated
51.48	2.3	51.47	1	Fe lacking
52.60	1	52.63	1	Probably separated. λV < λ Fe
60.97	1+	60.95	1	Fe lacking
92.09	1.2	92.18	1	Fe lacking
92.55	2	92.50	3	Separated. λV > λ Fe
4099.93	3.4	4099.94	2	Fe lacking
4105.32	3	4105.35	2	
07.61	1.2	07.65	5	Perhaps separated. λV < λ Fe
08.36	2	08.30	1	Fe lacking
09.94	3.4	09.95	5	Coin. Belongs to V | Fe
11.93	4	11.92	2	Coin. Fe only a trace. The line belongs to Ti with K-R
12.47	1.2	12.54	2	Probably separated. λV < λFe
13.66	2.3	13.59	1	Fe lacking
15.32	3.4	15.41	2	
16.85	1.2	16.93	1	
18.73	2	18.69	6	Separated, λV > λ Fe
19.58	2	19.52	2	Separated. λV > λ Fe
20.70	2	20.66	1	Separated. λV > λ Fe
29.00	2	28.98	1	Fe lacking
32.14	3.4	32.22	6	Separated. λV < λ Fe
34.60	3.4	34.57	2	Separated? Fe faint
41.96	1.2	42.01	2	Separated. λV < λ Fe
42.75	1.2	42.81	2	Fe trace. Coin.?
52.81	2	52.85	1	Fe lacking
53.49	1.2	53.54	1	Fe trace; separated. λV < λFe
60.57	1+	60.66	1	Fe lacking
77.25	2—	77.23	1	
79.57	2.3	79.53	1	
91.71	2.3	91.79	1	
97.45	1	97.40	1	Coin.? Fe extremely faint
4198.78	2—	4198.82	2	Separated. λV < λ Fe
4210.55	1	4210.55	5	Separated and λV > λ Fe. The Fe line has λ = 10.49.
24.30	2	24.34	3.4	
29.87	2	29.93	1	Fe lacking

V λ	V i	Fe λ	Fe i	Remarks
4232.62	3	4232.64	1	Fe lacking
39.12	1.2	39.07	5	Widely separated. Fe line given too intense
40.53	2+	40.56	2	Separated. λ V < λ Fe
59.46	2	59.45	1	Fe lacking
69.92	2	69.95	1	Coin. ?
79.12	1.2	79.07	1	} Fe lacking
84.19	3	84.26	1	
86.57	2	86.64	1	
96.28	2.3	96.20	1	
4298.17	2.3	4298.22	3	Separated. λ V < λ Fe
4368.76	1.2	4368.74	1	} Fe lacking
69.25	1+	69.25	1	
79.38	4.5	79.43	2	
80.69	1.2	80.67	1	
84.37	1	84.45	1	
84.87	4.5	84.89	2	Fe trace
90.13	4.5	90.17	2	Fe lacking
91.84	1.2	91.75	1	Fe lacking
4395.40	4.5	4395.46	1.2	Fe trace
4400.74	4	4400.79	1	Fe lacking
06.80	4.5	06.81	1	Fe lacking
07.85	4.5	07.87	3.4	Separated. λ V < λ Fe
08.67	4.5	08.61	3.4	Separated. λ V > λ Fe
12.30	2	12.22	2	Fe lacking
16.63	3	16.63	1	Fe lacking
23.32	2	23.36	1	Fe line appears to lie in the middle
23.41				
24.10	1.2	24.08	1	} Fe lacking
25.86	2	25.86	1	
26.17	3	26.15	1	
38.02	3.4	37.95	1	
41.88	3.4	41.87	1	
52.19	4	52.29	1	
57.65	3.4	57.75	1	Separated
59.93	4	59.95	1	Fe lacking
60.47	4.5	60.55	1	Fe trace. Separated
74.21	3	74.20	1	Fe lacking
74.84	3.4	74.94	1	Fe lacking
90.95	2.3	90.95	2	Coin. Fe line faint
91.66	1	91.60	1	Fe lacking
4496.26	3	4496.27	2	Coin. Fe line faint
4509.49	2	4509.48	1	Fe lacking
14.36	2.3	14.36	2	Coin. ? Perhaps λ V < λ Fe
20.33	2	20.42	1	Fe trace. Separated
25.34	2+	25.34	4	Coin. ? Perhaps λ V < λ Fe
29.80	2.3	29.82	3	Separated. λ V < λ Fe. Fe line inconspicuous.
37.88	2	37.81	1	Fe trace. Coin. ?
79.38	2.3	79.37	1	Fe lacking
83.96	2	84.00	2	Fe trace. Probably λ Fe > λ V
86.54	4.5	86.53	1	} Fe lacking
4594.27	4.5	4594.32	1	
4606.33	2.3	4606.41	1	

V λ	V i	Fe λ	Fe i	Remarks
4618.96	1	4618.95	2	Separated. λ V > λ Fe. Fe line faint
26.67	2+	26.72	1	Fe lacking. The line 4626.72 belongs to Mn
4630.23	1	4630.29	3	Separated; λ V < λ Fe; $\Delta\lambda = 0.07$.
4705.26	2	4705.17	2	Widely separated
07.62	2	07.52	5	Widely separated
14.28	2.3	14.38	1	Fe lacking
30.57	2	30.48	1	
31.74	1.2	31.67	1	
37.91	1+	37.82	1	
4757.68	2.3	4757.77	2	Widely separated
4827.62	3.4	4827.64	1	Fe lacking
59.33	1.2	59.27	1	Fe lacking
4871.46	2—	4871.50	4.5	Coin.?
5157.27	1—	5157.75	1	Fe lacking
70.15	1+	70.15	1	
92.22	1	92.17	1	
93.18	2	93.17	1	
5395.58	2—	5395.66	2	Widely separated
5415.51	2.3	5415.50	6	Probably separated
88.18	2+	88.11	2	Separated. Fe line V. V.
5490.22	1.2	5490.17	1	Fe lacking
5585.00	1.2	5585.07	1.2	Separated. λ V < λ Fe
5592.67	3	5592.71	1	Fe lacking
5605.20	2.3	5605.19	1	
24.80	2.3	24.77	4.5	Coin.
5627.86	3.4	5627.79	1.2	Fe trace, doubtful
5707.26	3.4	5707.22	1.2	Coin.? Fe-line faint
27.25	4	27.27	1	Fe lacking
27.90	2.3	27.93	1	
5761.70	1.2	5761.77	1	

As in previous cases, I have also here been unable to find on my plates a considerable number of the faintest iron lines occurring with Kayser and Runge. If we add to these the pairs which could be separated on the double exposure with greater or less certainty, there remain in the above list only an unimportant number of pairs as to which any uncertainty still continues. Of these the following coincidences are specially pointed out, which, to judge by Kayser and Runge's intensities, must be regarded as belonging to both metals:

V λ	V i	Fe λ	Fe i
3578.01	1.2	3578.10	2
3593.48	2	3593.53	1
3703.71	3.4	3703.75	3
3898.16	3	3898.12	3.4

V		Fe	
λ	i	λ	
3906.89	2	3906.91	2
4109.94	3.4	4109.95	5
4111.93	4	4111.92	2
4490.95	2.3	4490.95	2
4496.26	3	4496.27	2
4514.36	2.3	4514.36	2
4525.34	2	4525.34	4
5624.80	2.3	5624.77	4.5

It should be remarked, however, that in case of some of these iron lines the intensity on my plate seems much less than given here, so that it is very probable that these are impurities in the iron spectrum of Kayser and Runge. Such a line is 4111.92, which also occurs with high intensity in case of titanium, and therefore is without doubt to be ascribed to an impurity of this metal in Kayser and Runge's list. There is probably an error of 0.1 tenth-meter in the case of the last pair, which could not be separated on the double exposure.

VANADIUM AND TITANIUM.

The comparison of the list of wave-lengths of these two metals, in conjunction with a close investigation of the double exposures, has led to the results in the following table:

V		Ti		Remarks
λ	i	λ	i	
3493.34	1	3493.44	1	Widely separated
3614.39	1.2	3614.35	2	Coin. Belongs to Ti
36.09	2	36.05	1	Probable coin. Belongs to V
44.88	1.2	44.87	2	Coin.
63.73	2.3	63.82	1	Separated
88.22	2.3	88.19	1	Coin. Belong to V
3692.37	3	3692.35	2	
3704.85	3	3704.84	1	
08.88	1.2	08.83	1.2	Separated
22.76	2	22.70	2.3	Probably separated. λV > λTi
66.58	1.2	66.60	1	Separated. λV < λTi
82.29	1	82.26	1.2	Separated. λV < λTi
3798.40	1.2	3798.47	1.2	Widely separated
3818.37	3	3818.38	2	Coin. Belongs to V

V λ	V i	Ti λ	Ti i	Remarks
3822.14	2.3	3822.16	2.3	Separated. λV < λTi
23.00	2+	23.03	1	Coin. Belongs to V
33.36	1+	33.33	2	Separated. λV > λTi
36.20	2—	36.22	1.2	Perhaps separated
40.56	2.3	40.48	1	Separated ?
40.88	3	40.90	2	Coin. Belongs to V
56.00	4	55.99	1.2	Coin. Belongs to V
3888.23	1+	3888.20	2	Separated. λV < λTi
3998.87	3	3998.77	4	Widely separated
4013.67	1	4013.72	2.3	Separated. λV < λTi
15.50	1	15.56	2	Separated. λV < λTi
90.70	3	90.73	1	Belong to V. 1191 also Ti
92.83	3	92.83	1.2	
95.64	3	95.65	1	
4099.93	3.4	4099.94	1.2	
4105.32	3	4105.31	1.2	
09.94	3.4	09.92	1.2	
11.93	4	11.91	2.3	
15.32	3.4	15.32	2	
16.65	3	16.64	1.2	Coin. Belongs to V
23.35	2	23.42	2	Separated
23.65	3	23.68	2.3	Appear separated. λV < λTi
28.25	3.4	28.20	2	Coin. Belongs to V
31.32	1	31.38	1.2	Separated. λV < λTi
34.60	3.4	34.60	1.2	Coin. Belongs to V
59.85	2.3	59.79	2.3	Separated. λV > λTi
69.42	1.2	69.46	2	Separated. λV < λTi
4183.46	1+	4183.45	1.2	Separated. λV < λTi
4227.90	2	4227.80	2	Separated
4315.00	1.2	4314.95	3.4	Separated. λV > λTi
53.02	3.4	53.01	1	Coin. Belong to V
79.38	4.5	79.40	2	
84.87	4.5	84.85	2	
90.13	4.5	90.11	2	
4394.01	1.2	4394.04	3	Separated. λV < λT
4400.74	4	4400.74	1.2	Coin. Belong to V
07.85	4.5	07.85	1.2	
08.35	4	08.39	1.2	
08.67	4.5	08.70	1.2	
16.63	3	16.70	2	Separated. λV < λTi
26.17	3	26.24	2.3	Separated. λV < λTi
41.88	3.4	41.86	1.2	Coin. Belongs to V
44.40	3.4	44.41	1.2	Coin. Belongs to V
57.65	3.4	57.59	3.4	Separated
95.16	1.2	95.19	3	Separated. λV < λTi
96.26	3	96.33	3	Widely separated
4515.75	1.2	4415.76	1.2	Perhaps separated
49.82	3	49.79	3	Separated. λV < λTi
4594.27	4.5	4594.28	1	Coin. Belongs to V
4684.64	2	4684.68	1.2	Separated. λV < λTi
4731.42	1.2	4731.33	2.3	Widely separated
98.12	1.2	98.13	2	Coin.
4799.94	2+	4799.95	2.3	Coin.
4819.22	1.2	4819.20	1.2	Perhaps separated

VANADIUM AND CHROMIUM.

The majority of the approximate coincidences in the spectra of vanadium and chromium are due to independent lines, as shown in this table:

V λ	V i	Cr λ	Cr i	Remarks
3574.92	1	3574.93	2.3	Probably separated. λ V < λ Cr
3649.14	2	3649.12	3	Coin. Belongs to V | Cr
80.26	3	80.34	1	Widely separated
87.61	2.3	87.65	2.3	Probably separated. λ V < λ Cr
88.22	2.3	88.24	1	Coin.
3696.00	3	3696.02	1	Coin.
3790.62	2	3790.61	2	Coin.
3806.93	2	3806.97	2	Separated. λ V < λ Cr
17.98	1.2	17.97	1.2	Coin.
20.10	2+	20.11	1	Coin.
21.63	2	21.71	1.2	Widely separated
22.14	2.3	22.22	1	Separated
36.20	2	36.22	2	Separated. λ V < λ Cr
49.48	2	49.48	2.3	Perhaps λ V < λ Cr
52.27	1	52.33	2	Separated
3894.19	2	3894.20	3	Coin. Belongs to V | Cr
3963.77	2	3963.82	3.4	Separated. λ V < λ Cr
3992.95	3	3992.95	2.3	Slightly separated. λ V < λ Cr
4051.48	2.3	4051.47	1.2	Coin. Belongs to V | Cr
4067.90	1.2	4067.94	1	Cr line lacking
4120.70	2	4120.78	2	Widely separated
52.81	1.2	52.89	1.2	Widely separated
4197.45	1	4197.38	2	Separated. λ V > λ Cr
4200.35	2	4200.27	2	Widely separated
04.67	1	04.61	2	Separated. λ V > λ Cr
16.52	1	16.50	2	Perhaps λ V < λ Cr
34.70	2.3	34.64	1.2	Probably λ V > λ Cr. $\Delta\lambda > 0.06$
39.12	1.2	39.08	2.3	Coin.
55.60	1.2	55.65	2	Separated. λ V < λ Cr
62.32	2	62.27	1.2	Separated. λ V > λ Cr
4297.86	2.3	4297.91	2.3	Separated. λ V < λ Cr
4312.56	1+	4312.65	1.2	Widely separated
73.40	2	73.41	3	Separated. λ V < λ Cr. $\Delta\lambda > 0.01$
75.47	2	75.52	2.3	Perhaps λ V < λ Cr. $\Delta\lambda < 0.05$
80.69	2	80.73	1	Cr line hardly visible
4391.84	1.2	4391.90	2.3	Widely separated
4423.41	2	4423.46	1.2	Separated. λ V < λ Cr
28.67	3	28.71	2	Coin. Belongs to V | Cr
59.93	4	59.95	2+	Coin. Belongs to V | Cr
97.03	2+	4497.02	3.4	Coin. Belongs to V | Cr
4531.01	2+	4530.92	4	Widely separated
45.60	3.4	45.51	2.3	Widely separated
4583.96	2	4584.02	1.2	Cr line lacking
4600.34	1.2	4600.25	2.3	Separated. λ V > λ Cr
48.08	1	48.00	1.2	V line lacking
49.08	1.2	49.04	2.3	Probably separated. λ V > λ Cr
54.84	1.2	54.90	2.3	Widely separated

V λ	V i	Cr λ	Cr i	Remarks
4666.33	2+	4666.35	2.3	Separated. λV<λCr. Δλ>0.02
69.50	1+	69.50	2.3	Probably separated. λV<λCr
4681.07	1.2	4681.01	2	Separated. λV>λCr. Δλ<0.06
4706.34	2.3	4706.25	1.2	Widely separated
17.85	2.3	17.87	1.2	Separated. λV<λCr
54.13	2.3	54.10	1	Separated. λV>λCr
57.49	1.2	57.55	2	Separated
4766.80	2.3	4766.77	2	Coin.
4831.80	3.4	4831.79	1.2	Coin. . Belongs to V
4851.65	4	4851.65	1.2	Cr line extremely faint. Coin.?
5139.74	2—	5139.82	2.3	
5192.22	1	5192.17	2.3	
5225.97	1.2	5225.98	1.2	

The following pairs, strong in both spectra, show exact coincidence, and therefore may be provisionally assigned to the two metals:

V		Cr	
3649.14	2	3649.12	3
3790.62	2	3790.61	2
3894.19	2	3894.20	3
4051.48	2.3	4051.47	1.2
4428.67	3	4428.71	2+
4459.93	4	4459.95	2+
4497.03	2+	4497.02	3.4
4766.80	2.3	4766.77	2

In addition to these coincidences a few occur from which we might infer an impurity of the chromium by vanadium, on account of the very slight intensity of the component ascribed to chromium; this seems to me hardly probable, however, since the most characteristic groups of vanadium are not found in chromium. Such lines are:

V		Cr	
3688.22	2.3	3688.24	1
3696.00	3	3696.02	1
3820.10	2.3	3820.11	1
4380.69	2	4380.73	1
4831.80	3.4	4831.79	1.2

VANADIUM AND MANGANESE.

In the comparison of these two spectra I have found only a small number of lines, with nearly identical wave-lengths.

These were, almost without exception, separated on the double exposures.

V λ	V i	Mn λ	Mn i	Remarks
3578.01	1+	3577.99	3.4	Coin. Belongs to V | Mn. Other intense Mn lines are entirely lacking in V spectrum
3680.26	3	3680.32	1	Separated. λ V < λ Mn
3719.06	1+	3719.04	2.3	Coin.? Belongs to Mn
3806.93	2	3806.84	4.5	Widely separated
3886.36	1	3886.42	2.3	Separated
3997.30	1.2	3997.34	1	Separated. λ V < λ Mn
4052.60	1	4052.62	2	Coin. A common impurity?
4090.70	3	4090.73	1+	Probably separated. λ V < λ Mn
4123.35	2—	4121.41	1.2	Separated. λ V < λ Mn
23.65	3	23.68	1.2	Separated. λ V < λ Mn
31.32	1	31.26	2.3	Separated. λ V > λ Mn
4149.02	1.2	4148.94	2.3	Widely separated
4261.37	2—	4261.45	1.2	Widely separated
4284.19	3	4284.22	2.3	Appear separated. λV < λMn
4408.35	4	4408.28	1.2	Widely separated
57.65	3.4	57.71	3	Widely separated
4460.47	4.5	4460.55	2.3	Widely separated
4626.67	2+	4626.74	2	Separated

VANADIUM AND COBALT.

The approximate coincidences are here also found to consist of independent lines, as shown in the following table:

V λ	V i	Co λ	Co i	Remarks
3489.63	1	3489.54	4	Widely separated
3520.18	2	3520.20	3	Separated. λ V < λ Co
3529.90	2—	3529.92	4.5	Separated. λ V λ < Co
3708.88	1.2	3708.96	2.3	Widely separated
40.38	1.2	40.31	2	Widely separated
3777.63	1	3777.65	2	Separated. λ V < λ Co
3820.10	2+	3820.02	2	Widely separated
32.97	1+	33.02	1.2	Separated. λ V < λ Co
70.72	1+	70.65	2	Separated. λ V > λ Co
3894.19	2	3894.21	5	Separated. λ V < λ Co
3910.01	3	3910.08	3.4	Widely separated
25.36	2+	25.32	1.2	Separated. λ V > λ Co
75.51	1	75.48	1.2	Separated. λ V > λ Co
3979.59	2—	3979.65	3	Widely separated
4023.50	2	4023.54	1.2	Coin. Foreign line?
35.77	2	35.73	3.4	Separated
4092.55	2	4092.55	4	Perhaps separated, and λ V > λ Co
4104.55	2	4104.57	2	Separated. λ V < λ Co
4104.92	2	4104.89	2	Separated. λ V > λ Co

V λ	V i	Co λ	Co i	Remarks
4270.49	2	4270.58	1.2	Widely separated.
4298.17	2.3	4298.14	1.2	Separated. λV > λCo
4320.46	1+	4320.53	1.2	Separated
4379.38	4.5	4379.37	1.2	Probably separated, and λV λ < Co
4416.63	3	4416.63	1.2	Impossible to separate. Perhaps λV < λCo
36.31	3.4	36.37	1.2	Separated. λV < λCo
38.02	3.4	38.05	1	Only a trace of Co
4467.04	2	4467.04	3.4	Slightly separated. λV < λCo
4514.36	2.3	4514.33	2.3	Separated. λV > λCo
28.20	2.3	28.12	2.3	Separated
49.82	3	49.80	4	Slightly separated, but λV < λCo
4588.94	1+	4588.85	2	Separated. λV > λCo
4607.40	1.2	4607.46	2	Co line hardly visible
14.08	1	14.18	2	V line lacking
24.62	2+	24.70	1.2	Separated
4640.92	2	4640.99	1.2	Separated. λV < λCo
4721.70	2.3	4721.61	1.2	Separated
37.91	1+	37.95	2.3	Separated. V line faint. λV < λCo
42.79	2	42.76	1	The Co is lacking on the comparison plate
4793.10	2	4793.03	4	Separated. λV > λCo

VANADIUM AND NICKEL.

A comparison of vanadium and nickel yielded only three cases of coincidence in which the contamination of the first metal by the latter will be suspected, viz., at 3486.05, 3609.45, 3793.76. I have, however, provisionally retained the lines in question with vanadium, since a number of other strong nickel lines are entirely lacking in the vanadium spectrum.

λ	i	Ni λ	Ni i	Remarks
3486.05	1	3486.04	2.3	Perhaps separated
3533.85	3	3533.89	1	Separated. Ni line broad and diffuse. i > 1
3609.45	1.2	3609.44	2.3	Perhaps separated, and λV < λNi
3644.05	1+	3644.13	1	Widely separated
3715.62	2	3715.61	1.2	Coin. Ni line faint
3793.76	1.2	3793.75	3	Coin.
3832.97	1+	3833.02	2	Separated. λV < λNi
3912.36	2.3	3912.44	1.2	Widely separated. V line sharp. Ni diffuse
3913.03	2—	3913.12	2	Widely separated
3973.79	2—	3973.70	4	Widely separated
4143.02	1+	4143.12	1	
4307.33	2.3	4307.40	1.2	Widely separated
4356.10	2.3	4356.07	2	Separated. λV > λNi
4423.32	2	4423.24	1.2	Widely separated
4462.56	3.4	4462.59	4	Separated. λV < λNi
4606.33	2.3	4606.37	2.3	Separated. λV < λNi
4786.70	3	4786.66	3	Somewhat separated

(*To be continued.*)

Reviews.

Untersuchungen über die Spectra von 528 Sternen. H. C. Vogel und J. Wilsing. *Publicationen des Astrophysikalischen Observatorium zu Potsdam.* No. 39. Bd. XII, Stuck 1. Pp. 73. Engelmann, Leipzig, 1899.

With the systematic mode of presentation and fullness of detail that has made the Potsdam Publications the models of their kind, this work gives the results of the investigations of the photographic spectra of the brighter northern stars belonging to spectral Class I. The photographs were made by Professor Wilsing, with a small one-prism spectrograph attached to the 13-inch astrographic refractor, chiefly during the years 1894 to 1897; the examination of the negatives with a magnifying glass and the classification of the spectra was the work of the two authors together; while the measurement of the spectra and the comparison with the results of other observers was made by Professor Vogel.

In the introduction a rather unfavorable opinion is expressed of the sufficiency of the photographic method, as contrasted with visual observations, for distinguishing between spectra of Types II and III, and for differentiating between Types IIIa and IIIb. While hardly agreeing with this opinion, in view of the recent great improvements in sensitizing photographic plates, and of the actual results obtained at the Yerkes Observatory in photographing spectra of the two latter types (this Journal, August 1899), we may heartily assent to the statement of the advantage of the photographic plates for studying spectra of Type I.

Upon the discovery of helium and the accurate determination of its spectrum by Runge and others, during the progress of this work, Professor Vogel applied the new results in extending, and making more precise, his well-known classification of stellar spectra. This is given in some detail, and although his paper on the subject has already appeared in this Journal (**2**, 333, December 1895), it may be well to

recall the new features of the system. Class Ia now receives three subdivisions, essentially as follows:

Ia1. Spectra in which only the broad and strongly developed hydrogen lines appear.

Ia2. Those containing other metallic lines, especially of calcium, magnesium, and sodium, but no lines of helium. K is sharply bounded, but does not reach the breadth of the hydrogen lines. Lines of other metals are faint.

Ia3. K is of nearly equal intensity to the hydrogen lines; is rarely sharply bounded; or may be broader and stronger than the hydrogen lines. Helium lines cannot be seen, but numerous and strong lines of different metals, particularly of iron, appear. This subclass constitutes the transition to Class II, in which the hydrogen lines are no longer dominant, and only the calcium lines H and K are striking on account of their extraordinary breadth and diffuseness.

Ib. Spectra characterized by the presence of the helium lines, in addition to conspicuous hydrogen lines, and more or less lines of calcium, magnesium, sodium, and iron.

Class Ic is now also subdivided, into

Ic1. Spectra with bright hydrogen lines.

Ic2. Those having bright lines of helium, calcium, magnesium, and other metals in addition to those of hydrogen.

As good examples of the different subclasses we may cite the following stars:

Ia1. λ Bootis; ϕ Draconis; β Cygni, *seq.*; λ Cygni.

Ia2. α Cygni; β Aurigae; β Equulei.

Ia3. ζ Leonis; τ Cygni; β Cassiopeiae; δ Geminorum; α Canis Minoris.

Ib. γ Orionis; γ Pegasi; η Lyrae.

Ic1. Pleione (one component).

Ic2. β Lyrae (one component).

It is distinctly stated that the discrimination between Ia1 and Ib, and Ia1 and Ia2 offers the most difficulty, and that with strong dispersion, and good conditions generally, these spectra would presumably show the additional lines characteristic of subclasses Ib and Ia2, thus leaving Ia1 without any representatives, so that it could be dropped from the classification.

It is also pointed out that the new classification is adapted as closely as possible to the original form, so that the new first type stars with

bright lines, which modern views assign to the earliest stage of development, are retained under Ic rather than made to precede Ia. This is certainly a logical procedure, and reduces the confusion which might otherwise ensue. The reviewer adheres to the opinion that all schemes of stellar classification are at present provisional, and that it will be many years before a radically new and improved order of succession can be established. Such a classification ought to be based on the results obtained with the highest instrumental power attainable, including all the measurable radiations received from the bodies — electrical (if any), thermal, actinic, visual. Meanwhile the reviewer regards Vogel's classification with its present extension as the best system for practical use.

The spectra themselves, on which this research was based, extended from about λ3800 to λ4500 with almost uniform sharpness, due to the fact that the collimator and camera lenses were achromatized in precisely the same manner as the photographic refractor to which the spectrograph was attached.

The range from λ3700 to λ4480 was 10 mm; the most convenient breadth for measuring was 0.2 mm; the average exposure was from 12 to 15 minutes. The slit was accurately set in the focus of the objective for $H\delta$ (λ4102). An arrangement was provided for furnishing a comparison spectrum by a vacuum tube, but was seldom used. A comparison spectrum could also be obtained by bringing a star of known spectrum immediately above and below the center of the slit before and after the exposure on the star to be investigated. Guiding was exceedingly accurate and easy with the 9-inch visual telescope of the photographic refractor.

The work falls in three parts: I. The catalogue of the observed spectra; II. Measurements on plates of 130 stars; III. Comparison with the results of other observers.

The catalogue gives the name, magnitude, position for 1900, and date of plate and type of spectrum, together with abbreviated but readily intelligible remarks. One good plate only was taken of a star, unless the object appeared for some reason of especial interest. Among the 528 stars, 66 of Class II and 3 of Class III fell outside of the original scope of the investigation, which was the study of spectra of Class I. Omitting these and the stars whose spectra were too faint for inclusion in the classification, and those which could not be assigned

with certainty to any of the subclasses, the remaining 437 were distributed as follows:

Ia1 . . . . 44.	Ia2 . . . . 168.	Ia3 . . . . 68.	Ib . 100.
Ia1 to Ia2. 9.	Ia2 to Ia3. 16.	Ia3 to IIa. 19.	Ic . . 1.
Ia2 to Ia1. 3.			
Ia2 to Ib . . 5.			

Double spectra: Ia1 and Ic1, 1; Ib and Ic 2, 2; Ib and ? Ic1, 1.

The remarks include data as to strength, character, and number of the lines, separately for the hydrogen and for the metallic lines, with estimates of the comparative appearance of H (including $H\epsilon$) and K. Exclamation points attract instant attention to conspicuous examples of types. From this column, and the extended notes accompanying the measures in part II, we extract interesting details of some of the notable spectra.

K is lacking in the spectrum of ϕ Persei, of which towards 90 plates were taken. No lines at all were visible on many plates. The spectrum is considered variable. No mention is made of the detection of bright $H\beta$ and $H\gamma$, originally discovered by Campbell, which are double (as is always the case with γ Cassiopeiae) on a good plate obtained with the 40-inch refractor by the reviewer. Hence the assignment of this star to Class Ia 2?—of course the only legitimate assignment on the basis of the plates and apparatus employed—is incorrect; more powerful dispersion shows it to belong to Class Ic1. A similar remark would apply to ψ Persei, and some other stars of this variety.

The spectrum of γ Cassiopeiae appeared purely continuous on the five plates obtained. It is not surprising that the dark lines in this spectrum were not seen, for it is vexatiously difficult, even with powerful apparatus, to obtain the necessary contrast for revealing them. The objective prism has a singular advantage in this respect, as shown by the results at Harvard and Stonyhurst. However, the presence of the dark lines has been abundantly confirmed by the spectrographs of the Allegheny, Lick, and Yerkes Observatories. In view of the complexity of the spectra of stars of the γ Cassiopeiae type, it will no doubt be necessary in future to discriminate more sharply in regard to the varieties of Class Ic.

We further note that in the star in Cassiopeiae, 37 Hev., K was double on three plates; this is also found to be the case for β Aurigae. It was suspected in the stars ω Ursae Majoris, 68 Ophiuchi and 109

Virginis. Thirteen plates of the last star were obtained, and on several plates K was double, or, at any rate, two distinct lines were seen at the position of K. On some plates of ζ Ursae Majoris the hydrogen lines were double or brightened up in the center.

The spectrum of Algol showed no changes in character having relation to the light period, but in some cases the hydrogen lines were brightened up in the center.

Numerous plates were obtained of α Cygni, as slight changes were suspected in its spectrum.

The micrometric measures of wave-lengths, made on the spectra of 130 of the stars, were reduced graphically from numerous solar and metallic spectral plates. They are given to the tenth-meter, and are based on Rowland's scale. In most cases a single measurement of a spectrum was sufficient to certify to the presence of helium lines, and an agreement within $\pm$ 1.5 tenth-meters was regarded as adequate for identification — an accuracy which all will agree was abundant for the purpose. A valuable accompaniment to the measures is the estimate, on a decimal scale, of the intensities of the lines.

The average number of lines measured was, of course, not large in this class of spectra — perhaps twenty — but in the case of α Cygni as many as fifty-five lines were determined. β Lyrae and P Cygni are both classified as "Ib and Ic 2" and are described at some length. Comment on these extraordinary spectra would lead us at once to transcend the bounds of a review.

A tabular exhibit is made of the helium lines found in stars of Class Ib, with their intensity in the spectrum of each star thus measured; and another table summarizes the lines not due to helium or hydrogen, with the stars in which they are found.

The results obtained are compared with the "Draper Catalogue" and with Miss Maury's "Spectra of the Brighter Stars." After pointing out cases where the "Draper Catalogue" gives discordant type assignments of the same bright star from different plates, and remarking that this is not to be wondered at, in view of the difficulty of securing a proper exposure for plates containing so many stars of different magnitude Professor Vogel comments that "on the average, however, the comparison with our results gives a right good agreement, and full recognition surely cannot be witheld from the great undertaking of the production of a catalogue of the spectra of 10351 stars." While gracefully acknowledging the value of Miss Maury's work he considers

that the classification is carried decidedly too far, and loses clearness. Tabular statements, arranged by types, compare the three catalogues mentioned, and complete the memoir. As a whole this little volume affords an admirable illustration of what valuable work can be done with comparatively small, but finely adapted and adjusted, instruments, in (it should be added) the hands of experts. Those portions of the work, in part referred to above, for which the dispersion was inadequate, can be fully investigated with the splendid equipment now happily available for the future stellar spectroscopic work of the Potsdam Observatory. E. B. F.

Comparative Photographic Spectra of Stars to the 3½ Magnitude. By FRANK MCCLEAN. *Phil. Trans.*, A. **191**, 127–138, 1898. 17 plates.

Spectra of Southern Stars. By FRANK MCCLEAN. Pp. 16; 12 plates. London: Edward Stanford, 1898.

THE first of these two works is a collection of reproductions of 160 photographs of spectra of northern stars, accompanied by a brief discussion of their classification and distribution. No description is given of the instrument with which the plates were obtained, but from an earlier note by the author in *Monthly Notices* we may infer that an objective-prism of 12 inches aperture and 20° angle, mounted on a refractor of equal aperture and 11 feet 3 inches focal length, was employed.

As the ordinary data given with spectral plates, such as the date and duration of exposure, are also omitted, the intention of the work would seem to be pictorial and qualitative rather than metrical and quantitative. Regarded in this way, it is of decided value, being the only memoir to which one may turn for a photograph of the spectrum of each of the brighter stars. The plates are accompanied by representations of the spectra of several of the elements, for purposes of comparison and identification, and an approximate scale of wave-lengths is given.

The author divides the celestial sphere into eight zones of equal area referred to the galactic poles, and briefly examines the distribution of the different types of spectra in these zones. He subdivides Secchi's first type into three "divisions," and makes divisions IV, V and VI

correspond to Secchi's types II, III and IV. A tabular statement is given of the arrangement of the stars on the plates which follow, together with the classification of each star according to Secchi, Vogel, Pickering, and Lockyer.

In an examination of the distribution of stellar spectra the arrangement of the successive spectra according to location in the galactic areas, and then according to type, is no doubt necessary, but for convenience of reference, an arrangement by types alone would be more convenient.

The plates themselves, covering the region from about λ 3850 to λ 4900, give evidence of the great efficiency of the objective-prism, although it is probable that the reproductions hardly do justice to the originals. There is clearly much room for improvement in guiding the telescope during the exposures, as the star lines are greatly inclined or curved on some of the spectra, thus requiring considerable ingenuity in fitting them together, one below the other, so that the scale of wave-lengths could apply to all the spectra on a sheet. The plates in the second memoir, which is an extension of the first to the southern skies, show a very great improvement in this regard. The spectral lines are here always nearly vertical, and the appearance is much improved.

The second series of plates was made by the author during a visit to the Cape between May and October 1897, the objective-prism used in England for the first series being attached to the astrographic telescope of the Cape Observatory. The examination of the distribution of the different types is made in the same manner as in the first series, but the classification assigned by the other observers is necessarily omitted for these southern stars.

The chief interest in this memoir, aside from the general value of an accessible reproduction of the spectra of all the brighter stars, lies in the author's discovery of the presence of oxygen in the spectrum of β Crucis. The wave-lengths of the lines in the spectrum were measured and reduced by a cubical interpolation formula, and a table gives a comparison of these with the lines of helium, hydrogen and oxygen. Any lingering doubt as to the certainty of the coincidences with the oxygen spectrum is dispelled by the careful measurements made by Dr. Gill on spectra obtained with a large spectrograph and published in the last number of this JOURNAL.

Another table gives a list of the lines visible in the spectrum of γ Argus, over fifty in number. The author identifies four of these

with lines of the series discovered by Pickering in the spectrum of ζ Puppis. As two of these coincide with helium lines, which are shown by the author to be abundant in the spectrum, this identification perhaps required confirmation by measures on a plate taken with a spectrograph and having a suitable comparison spectrum.

E. B. F.

Annales de l'Observatoire d'Astronomie Physique de Paris. Tome premier. Paris, Gauthier-Villars et Fils. 4to pp. 122, plates XXI.

THE establishment of a national astrophysical observatory by the French government was a natural sequel to the able work of M. Janssen at the total solar eclipse of 1868. The discovery in that year of a method by which the spectrum of the chromosphere could be observed in full sunlight created the greatest enthusiasm, and the spectroscopic study of the Sun was undertaken in many European and American observatories. In Italy, thanks to the labors of Secchi, Tacchini, and Lorenzoni, there was established the *Società degli Spettroscopisti Italiani*, which gave every encouragement to astrophysical research. In England, Huggins made important contributions to our knowledge of the Sun, and did much to develop a method the potentiality of which he had long before foreseen. Lockyer, whose successful attempts to apply the spectroscopic method are also well known, sought in the study of solar phenomena data to support his hypothesis of the dissociation of the elements. In the United States Young entered upon the well-planned and well-executed series of observations which has added so much to our knowledge of the spectrum of the chromosphere, and Langley undertook his important solar investigations at the Allegheny Observatory. In Germany, Zöllner and Vogel recorded a great variety of interesting phenomena, and contributed to the improvement of the solar spectroscope. In France, however, as M. Janssen tells us in the historical sketch which introduces the present volume, the instrumental equipment required for solar research was lacking. A government project to establish a new observatory for M. Janssen might have been carried into immediate effect had not the Franco-Prussian War suddenly directed the attention of every Frenchman to the problem of the national defense. The outcome of the war, and the conditions which it entailed, were unfavorable to the development of the plan to establish

a national astrophysical observatory. Nevertheless the project was not forgotten. In July 1874 it was discussed in the National Assembly, and a few weeks later the Academy of Sciences was requested to report as to the advisability of founding an institution exclusively devoted to astrophysical research. The report of the special committee of the Academy, which was presented by M. Faye, may be found in the present volume of the *Annales*. After describing the first step in astronomical physics, which is credited to Arago, the report outlines the rise and progress of spectroscopy, refers to the discovery of the gaseous nature of the prominences by Janssen and Rayet at the eclipse of 1868, dwells on the nature and importance of astrophysical research, and concludes with a strong recommendation for the establishment of an astrophysical observatory in the immediate vicinity of Paris.

As a result of the recommendations of this report the government voted an annual grant of fifty thousand francs, which was devoted to the establishment and maintenance of a small observatory provisionally erected on the boulevard Ornano. The park surrounding the old chateau on the terrace at Meudon was selected as the permanent site, and preparations were made to occupy it as soon as it had been evacuated by the French troops, who at that time used the building for barracks. The sum necessary to reconstruct the chateau for observatory purposes and to purchase instruments, which amounted to 1,035,000 francs, was appropriated by the Senate in three equal parts in the years 1879, 1880, and 1881.

M. Janssen's historical sketch is followed by a description of the great dome and the principal instruments of the Observatory. The dome has a diameter of 18.5 m, and can be moved by electricity. The observing slit is provided with an adjustable canvas screen to protect the telescope from the wind. Observations are made from a platform, attached to the dome opposite the slit, which can be raised and lowered by means of an electric motor. The telescope, with visual and photographic objectives by the Henry Brothers, of 0.83 m and 0.62 m aperture respectively, is provided with a mounting by Gautier. The objectives are supported side by side in a tube of rectangular section, divided longitudinally by a sheet metal screen. The focal length of the visual objective is 16.16 m, while that of the photographic objective is 15.90 m. The mounting is provided with the usual adjustments. The telescope stands on a massive pier at a great height above the ground in the reconstructed chateau of Meudon.

The equipment of the Observatory includes the elaborate apparatus employed by M. Janssen in his studies of the absorption spectra of gases at various pressures and temperatures; a reflecting telescope of 1 m aperture and 3 m focus; and the photoheliographs with which have been obtained the remarkable photographs of the Sun described in the remaining portion of the volume.

M. Janssen's memoir on solar photography opens with a brief historical sketch of the work of Draper, de la Rue, Rutherfurd and others. The first astronomical photograph, one of the Moon taken only a few months after the publication of Daguerre's discovery, was due to William Draper. The Sun was first photographed by Fizeau and Foucault in 1845. On the advice of Sir John Herschel solar photography was first taken up systematically at Kew in 1858, where Warren de la Rue succeeded in securing a daily series of photographs having a diameter of 0.10 m, which were well adapted for the statistical study of Sun-spots. On account of the small size of the solar image these plates did not bring out the granulation of the photosphere and the details of the spots. The photographs of Rutherfurd and Vogel were more servicable for this purpose, and showed many important details. But it was reserved for M. Janssen to perfect at Meudon a photographic process capable of revealing the structure of the photosphere as it is rarely seen with powerful telescopes, employed under the best atmospheric conditions. This work was undertaken in 1874, in connection with the experiments on the use of photography made in preparation for the transit of Venus of that year.

The Meudon photoheliograph consists of an objective of 0.135 m aperture, by Prazmowski, mounted at the end of an adjustable wooden tube supported by a carriage on rollers. In the focal plane of the objective is a rapid exposing shutter, consisting of an adjustable slit in a metal plate which can be shot by springs across the axis of collimation. An amplifying lens mounted just beyond the exposing shutter gives an enlarged image of the Sun on a wet collodion plate at the lower end of the camera tube.

With this apparatus photographs of the Sun on a scale of 0.20 m, 0.30 m, 0.50 m and in a few cases 0.70 m to the Sun's diameter have been obtained. The diameter ordinarily employed is 0.30 m, as images of this size have been found to be most generally useful. M. Janssen believes the excellence of the photographs may be ascribed to:

1. The use of objectives made of selected glass, and achromatized

for a well-defined maximum of intensity in the spectrum of transmitted sunlight.

2. The employment of a special collodion having a maximum of sensitiveness at this point in the spectrum, and of exceedingly fine grain.

3. The considerable scale of enlargement.

4. The precautions taken to give a properly timed exposure, uniform for all parts of the image.

The photographs, of which several are reproduced in this volume, bring out in a most satisfactory manner the granulation of the photosphere, and afford material for the study of many important problems. M. Janssen considers the form of the grains to be more or less approximately spherical, while their diameter varies from one fourth to two seconds of arc. Larger masses are frequently met with, but they are shown by the best photographs to be composed of numerous very small granules. The diameters of the grains given by M. Janssen are in good agreement with the values previously obtained visually by Professor Langley with a 13-inch telescope. But unless a telescope of larger aperture than that mentioned in the text (0.135 m) was employed, it is difficult to understand how details of the photosphere having a diameter of only one fourth or even one third of a second of arc (p. 105) can be resolved on the photographs. For a circular aperture of this diameter, and light of wave-length 4000 tenth-meters, the theoretical resolving power of such a telescope is 0.75″. The remarkable details shown in Plate X are also apparently beyond the reach of a 5-inch objective. Was a larger objective used, or have unpublished experiments shown that the special photographic process employed is capable of recording only a small point at the center of the bright spot of the diffraction pattern, thus surpassing the eye itself? A fault of the volume under review is here illustrated. There is a noticeable lack of exact data, and one who wishes to make a detailed study of the instruments and methods finds it impossible to do so. Such omissions have been only too common in astrophysical literature, and have doubtless given rise to much of the criticism which has been directed against the subject by those who are accustomed to exact methods and complete discussions of all available data.

M. Janssen's opinion that the general form of the grains is spherical does not exactly coincide with the view of Professor Langley, who believes the grains to be the extremities of filaments, which are

seen at all their length in spot penumbrae. According to M. Janssen, however, the penumbral elements are themselves resolved into grains. In portions of the photosphere, where they are beaten down as if by a storm, the "grains" seem to be elongated, and in many cases they are blurred and indistinct. In fact, M. Janssen finds the whole surface of the photosphere to be dotted over with a network of these blurred regions, to which he has given the name *réseau photosphérique*. This phenomenon is beautifully shown in the remarkably fine plates which accompany the volume. The dimensions of the polygons which form the meshes of the net have been found to vary from 100″ to 120″, at times of maximum size, to 10″ or 12″ at their minimum. Photographs showing the *réseau photosphérique* in various stages of development accompany the volume. Some of these plates are truly extraordinary, and will repay careful study. The faculae are shown resolved into closely grouped bright grains, and the bridges and penumbrae of spots are also resolved into granular elements. In some cases the *réseau photosphérique* is almost altogether absent.

It was asked by some who examined the earlier photographs whether the phenomenon of the *réseau photosphérique*, ascribed by M. Janssen to regions of exceptional disturbance in the solar photosphere, may not be caused by disturbances in our own atmosphere. There has been ample time to submit the question to a rigorous test, and it is certainly to be presumed that such a test has been made. A word from M. Janssen might have set all doubts at rest in the minds of any who still consider the matter open for discussion, but the present volume contains no reference to the subject. The difficulty of obtaining two solar photographs of the requisite excellence within a time so short as to exclude the probability of change in the *réseau* is undoubtedly great, and might possibly be insuperable. But in the last edition of *The Sun* Professor Young states that M. Janssen has obtained such pictures, which leave no room for doubt as to the solar origin of the phenomenon. The publication of these photographs in the present volume would have added to its value, as without such positive evidence students of solar physics sometimes find it difficult to reply effectively to those who are inclined to consider the *réseau* a terrestrial phenomenon. The matter is further obscured by the difficulty of reconciling M. Janssen's explanation of the blurred regions of the *réseau* as due to disturbances in the photosphere with the fact that the grains are clearly and distinctly shown in the bridges and penumbrae

of exceptionally active Sun-spots (Plate XII). The discovery of the *réseau photosphérique* was an advance of so great importance to solar physics that all details of the subject are earnestly desired by workers in this field.

But while it can hardly be gainsaid that the volume might be improved by the addition of certain data, as well as by greater thoroughness of discussion, the reader cannot fail to accord a full measure of praise to the originator of this invaluable method of research. Already it has yielded numerous results of the greatest importance. In the future, particularly when employed in conjunction with other devices to facilitate solar observation, it should contribute still further to our knowledge of the Sun. G. E. H.

The Indian Eclipse, 1898. Edited by E. WALTER MAUNDER. Published by the British Astronomical Association. 8vo, pp. xii+172.

THE British Astronomical Association, which was founded in October 1890, has for its principal object the organization of possessors of small telescopes in the work of astronomical observation. The association sent an expedition of volunteer observers to Norway in 1896, where the sky was unfortunately cloudy. The present volume describes the observations of the Indian eclipse of 1898, made by a large number of the members.

Apart from the amply illustrated accounts of the observers' experiences, many of which are interesting narratives of travel, the book contains much that is valuable to students of solar physics. Mr. Evershed's spectroscopic observations were especially important. His instruments consisted of a prismatic camera of 2¼ inches aperture and 36 inches focus; a slit spectrograph containing two quartz prisms for the spectrum of the corona; and a large slitless spectrograph attached to a 6-inch telescope. The two former instruments were supplied with light by a 4-inch polar heliostat, and a 3¼-inch equatorial telescope, provided with a solar spectroscope, was employed for visual observations of the chromospheric spectrum, and to determine the proper moment to expose for the "flash." It is evident that only a skillful and cool-headed observer could hope to operate all of these instruments successfully, and this Mr. Evershed proved himself to be. Except for a single omission, the program of exposures was carried

out to its conclusion by Mr. Evershed alone. The remarkable photographs of the spectrum of the flash, reproductions of which accompany the report, are evidence that excellent judgment was shown in making the exposures, and that the adjustments of the instruments left nothing to be desired. Twelve successful photographs were secured in all. Of these the most interesting and important are the ones taken with the prismatic camera. These extend from λ 6000 to λ 3350, thus including most of the visual spectrum and the greater part of the ultra-violet besides. On one of the plates 218 lines can be counted between H and λ 3342, the extremity of the spectrum in the ultra-violet. The definition is excellent, and the wave-lengths of all the lines have been determined. Mr. Jewell, of Johns Hopkins University, has found three of the lines to be due to titanium. Most of the others are ascribed to iron, calcium, magnesium, etc. Thirty hydrogen lines are shown, the wave-lengths of which, for the most part, agree very accurately with the wave-lengths calculated from Balmer's formula. Beyond $H\omega$, where the lines are faint, the wave-lengths show a somewhat less satisfactory agreement with the theoretical values. The wave-lengths of a considerable number of lines in the visual spectrum, between H and D, have also been determined. The result obtained in the case of the green coronal line accords with the conclusions of Lockyer and Campbell, to the effect that this line is some fourteen tenth-meters more refrangible than the chromospheric line (1474 K) with which it has hitherto been identified. The reproduction of a photograph of the solar spectrum, which is given for comparison with the chromospheric spectrum, is hardly good enough for the purpose. Mr. Evershed states that, while a large number of conspicuous flash lines do not appear to be represented by dark Fraunhofer lines, the appearance can be ascribed in many cases to differences in intensity, the dark lines which are actually present being very faint.

Mr. Maunder's observations were made with a binocular, one of the eyepieces of which had been fitted with a direct-vision prism. His purpose was to ascertain the distribution of "coronium" in the corona. On account of the excessive brightness of the spectrum observed before totality, his eyes were not in a condition to permit the faint green image to be seen at first. When it became visible it appeared that the gas extended pretty uniformly about the Sun up to a height of about 160,000 miles, but that it exhibits no structure corresponding with that of the visual corona. This result confirms the

early observations of Tennant, who found that the green line suffered no interruption in the rifts of the corona.

The remainder of the book contains a large number of reports, many of which are valuable. Mrs. Maunder, using a Dallmeyer stigmatic lens of 1½ inches aperture and 9 inches focal length, secured photographs of the corona of remarkably great extent. In fact, the plates are said to show longer streamers (extreme length = 13.9 lunar radii) than have ever before been photographed. With a triple-coated plate she also obtained a distinct image of the corona 39 seconds after the end of totality. The great advantage of using triple-coated plates in photographing the corona is illustrated by this work and by the success of long exposures in showing the faint extensions of coronal streamers.

Excellent suggestions for those who intend to observe the eclipse of May 28, 1900, may be found in Mr. Maunder's discussion of the photographic results, and in the summary at the end of the volume. The British Astronomical Association is certainly to be congratulated, both on the success of its Indian eclipse expedition and on its good fortune in having so able an editor to arrange and discuss the results.

G. E. H.

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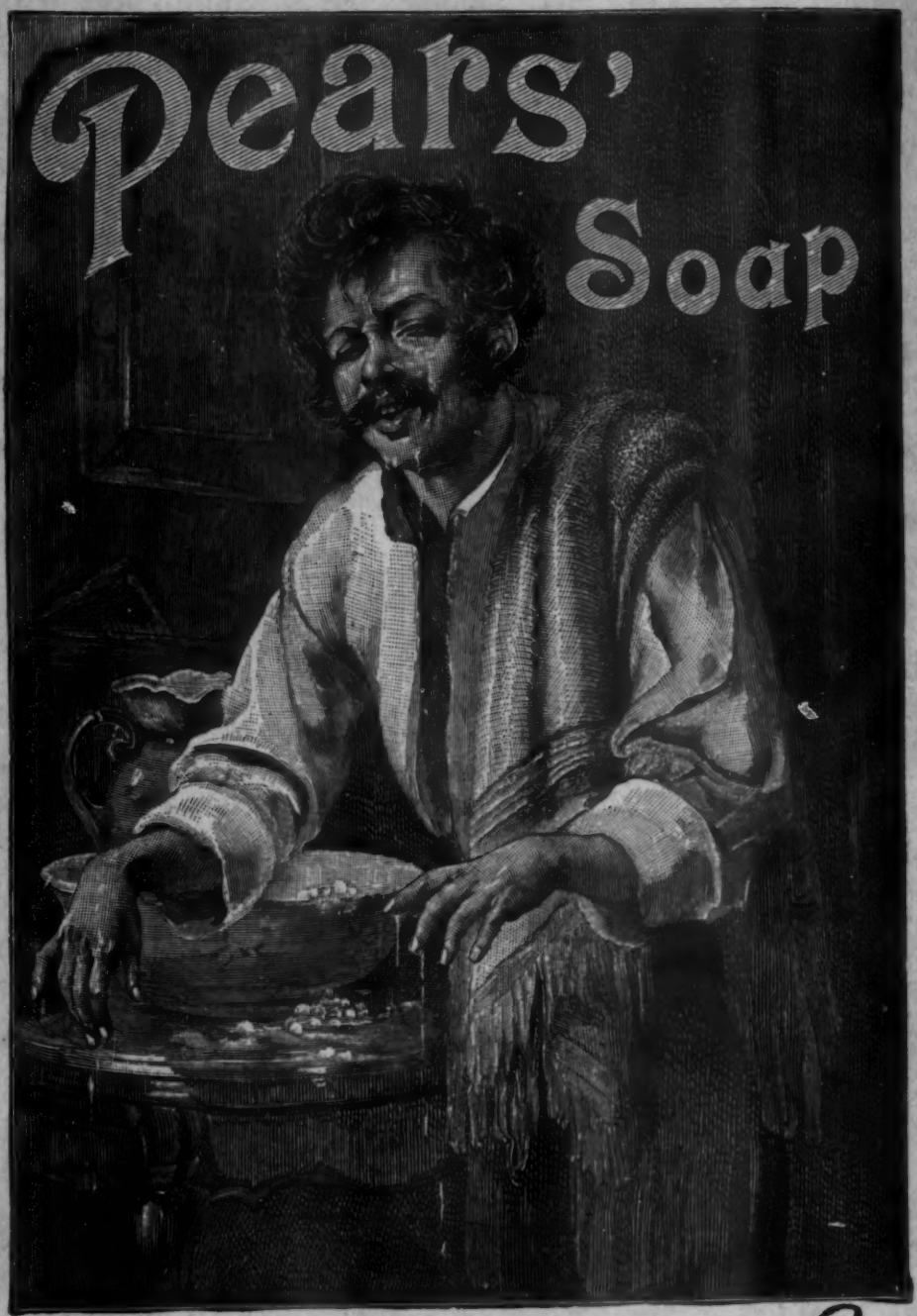

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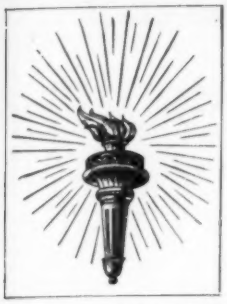

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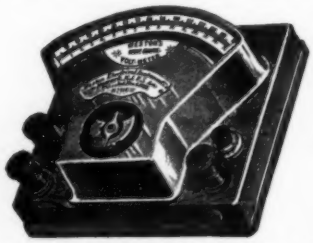

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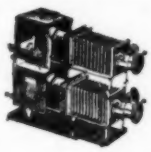

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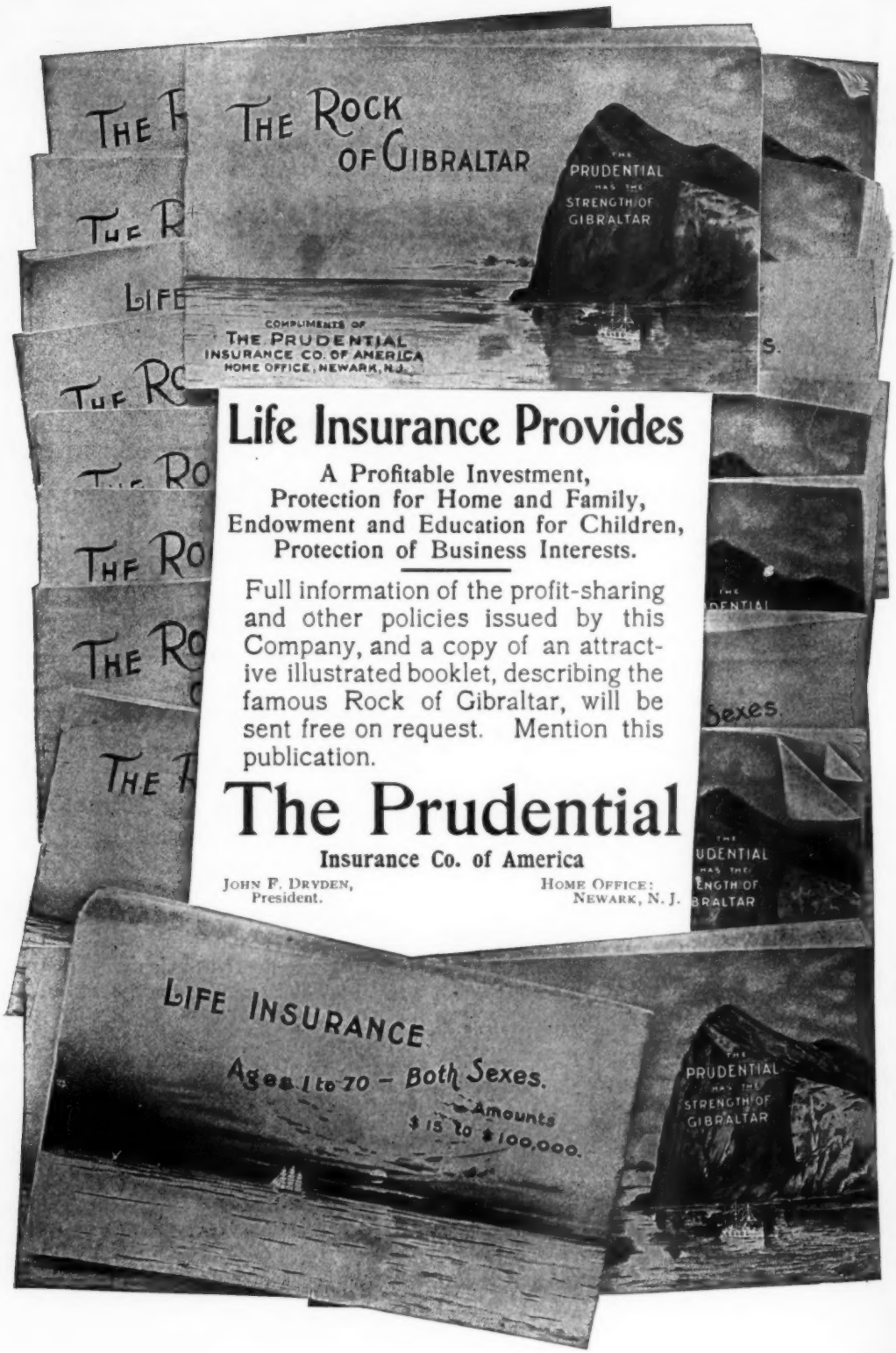
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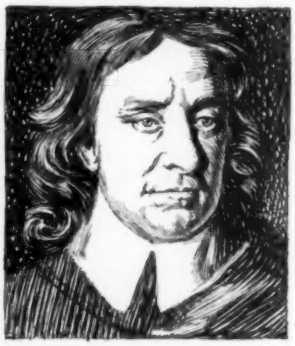

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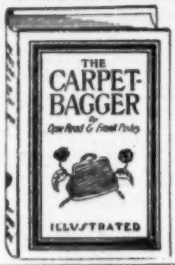

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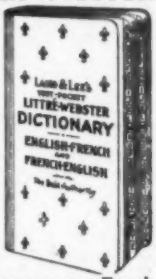

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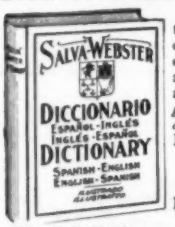

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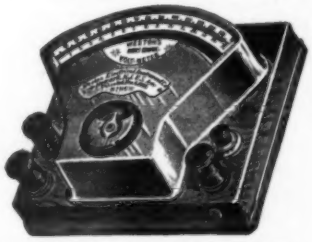

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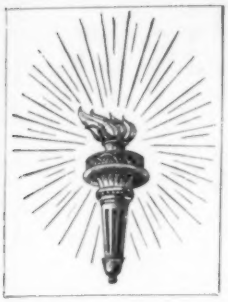

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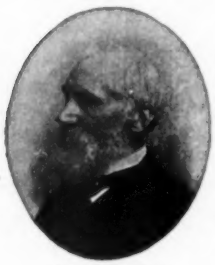
On the 23rd of March, 1898, *The Times* (London) announced that it had made arrangements with Messrs. A. & C. Black, the publishers of the ENCYCLOPÆDIA BRITANNICA, by which a special edition of that work was printed for *The Times*. The sets thus obtained were offered by *The Times* at a discount of over one-half from the regular price. In this way the original edition of the greatest of reference libraries, hitherto obtainable only by the wealthy, was brought within the reach of all. For exactly one year this offer of *The Times* remained open to the British public. When it was withdrawn, March 22nd, 1899, the enterprise had proven such a success, and the number of sets of the ENCYCLOPÆDIA BRITANNICA purchased was so great, that the printers and binders of Great Britain had been left far behind. The printing and binding orders consequent upon the sale far exceeded any that had ever been given before anywhere in the world. Over 500,000 volumes of the great work had actually been purchased. *The names of a few of the purchasers appear on the last page of this announcement.*



LORD KELVIN

The last English order has finally been filled, and *The Times* is therefore now in a position to offer the work in the United States. *The Times* has no doubt that there are thousands of persons here, just as there were in Great Britain, who have desired to possess a set of the *genuine* edition of the ENCYCLOPÆDIA BRITANNICA, but have been prevented from doing so by the price. To all such this offer of the work at less than half the publishers' original price will be most welcome.

A further reason for the offer of *The Times* is the desire to relieve the ENCYCLOPÆDIA BRITANNICA in the United States from a certain odium that has possibly become attached to it as a result of the many spurious, mutilated, or "photographed" editions which have hitherto been widely sold in America. Probably over 400,000 so-called sets of the ENCYCLOPÆDIA BRITANNICA have been sold in this country, far the greater portion of which were mutilated or uncopyrighted editions, from which Messrs. A. & C. Black, the publishers, who invested in the work over $1,100,000, received no benefit whatsoever. None of the editions sold in this country were genuine except those that were printed by Messrs. A. & C. Black. In view of all this, *The Times* has decided to offer in the United States a limited number of sets of the *genuine authorized* edition of the ENCYCLOPÆDIA BRITANNICA at the same price as in England, and with the *duty paid.*

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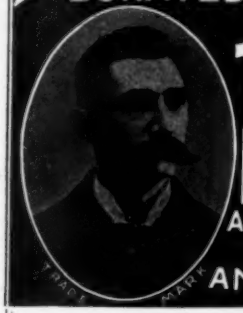

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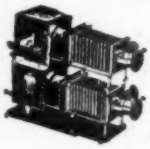

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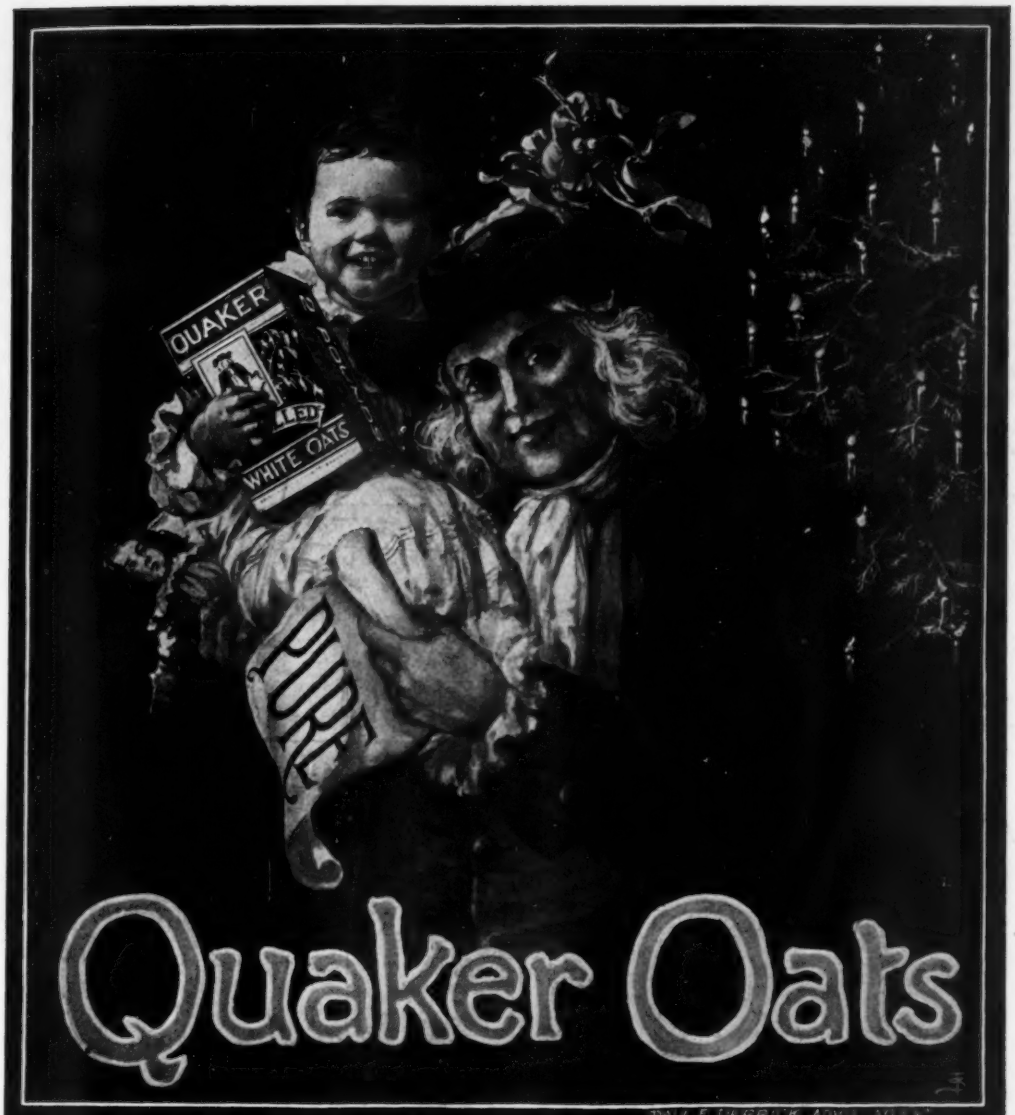

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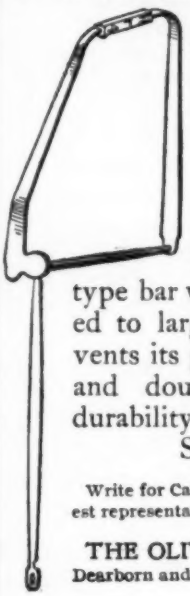

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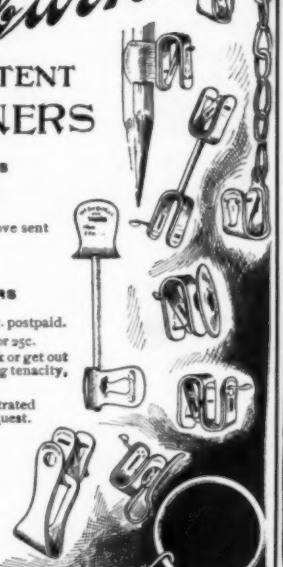

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